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Geological investigation of the Railroad Ridge diamicton, White Cloud Peaks area, Idaho.

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GEOLOGICAL INVESTIGATION OF THE RAILROAD RIDGE DIAMICTON, WHITE CLOUD PEAKS AREA, IDAHO

by

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ABSTRACT

The Railroad Ridge diamicton, capping four interfluves on the east flank of the White Cloud Peaks, Idaho, is one of many ridgetop deposits found throughout the American Cordillera. It is characterized by large granitic boulders in an unsorted matrix, a smooth, gently sloping surface morphology, and an estimated thickness of up to 520 feet (158 m). Previous investigators have tentatively regarded the Railroad Ridge diamicton as a glacial till. Several different hypotheses regarding depositional mechanisms are considered here; these include landslides, rockfalls, torrential streams, and saturated debris flows, such as mudflows and solifluction. Of these, the most reasonable alternative hypothesis is deposition by the action of mudflows, forming a fan morphology.

Size analyses of five unweathered matrix samples and the resulting statistical determinations of mean, standard deviation, and skewness were compared to the same parameters from other diamictons. The results, confirmed by discriminant function analysis, favor the hypothesis of deposition by fan-building mudflows over glacial action, although no modern analog is known. Sedimentologically, mudflows can have characteristics similar to those of tills: large boulders may be present, the matrix is unsorted, and stratification is generally lacking. Geomorphological evidence supporting the fan-building mudflow hypothesis includes:

1. the deposit's smooth, slightly concave surface profile;

2. crude layering of boulders and a possible buried paleosol parallel to the deposit's surface;

3. its position relative to the source area; and

4. the extreme thickness of the deposit.

Provenance data indicates that the Railroad Ridge diamicton occurring on the three southern ridges ("the Spur," Red Ridge, and "Trimline Ridge") has higher intrusive concentrations than that occurring on Railroad Ridge. The inverse spatial relationship is found for metasediment concentrations. Nowhere are extrusive lithologies common; most areas lack them completely. In some cases, provenance can also separate the Railroad Ridge diamicton from the valley tills deposited by the latest major glaciation.

The source area for the granitic component of the Railroad Ridge diamicton is the White Cloud stock. Prior to valley cutting, drainage from the quartz monzonite highlands must have moved in part across Railroad Ridge. A tentative reconstruction of the source area indicates the central portion had drainage divides further to the east. Headward erosion has since moved the divides westward and pirated drainage of the stock away from Railroad Ridge.

The age of the Railroad Ridge diamicton is probably Pliocene, as deduced from bounding geomorphic surfaces. The development of the post-Challis erosion surface on which the deposit rests took place over the course of the Miocene. The rejuvenation of the Salmon River system, causing the incision of the modern drainage in the study area, began no later than early Pleistocene. Deposition of the diamicton itself may have been a climatically induced event.

1 INTRODUCTION

Many areas of the American Cordillera exhibit unusual ridgetop diamictons adjacent to high peaks (Atwood, 1915; Alden, 1924; Blackwelder, 1931a; Richmond, 1957; Scott, 1973; Madole, 1982). While many such deposits are recognized as predating the last major valley-cutting episode, little research on their age or origin has been carried out. The Railroad Ridge diamicton, as it is here informally designated, is an example of such a ridgetop deposit. It is located in the White Cloud Peaks area, Custer County, Idaho, and is described in detail by Ross (1929; 1937; unpubl.). There exist many questions regarding the origin, extent, and age of this deposit. In order to place the Railroad Ridge diamicton in a climatic and tectonic framework, investigation based on sedimentological and morphological considerations has been carried out. This extends beyond the early research of Ross and later work by Tshanz and others (1974), who based their theories solely on observational evidence.

The Railroad Ridge diamicton has elicited controversy due to features inconsistent with such common alpine Quaternary deposits as valley glacial deposits, felsenmeer, rock glaciers, landslides, talus, and stream terrace deposits. These features are:

1. its postion capping four interfluves on the east side of the White Cloud Peaks at elevations up to 10,800 feet (3292 m);

2. the preponderance of very large granitic boulders in an unsorted matrix;

3. the extreme deposit thickness, greater than 500 feet (152 m), attained on the divide between Big Boulder and Jim Creeks;

4. the smooth, gently-sloping surface profile on Railroad Ridge and adjacent ridges; and

5. its obvious antiquity relative to late Pleistocene glacial and landslide deposits and the erosion of the current drainage pattern.

Results obtained from investigation of the Railroad Ridge diamicton can provide a basis for comparison to similar deposits throughout the Rockies. In turn, this may help to elucidate tectonic and climatic events of the late Cenozoic in the American Cordillera.

2 GEOLOGIC SETTING

2.1 GEOGRAPHY

The White Cloud Peaks are located in south-central Idaho and comprise the glaciated highlands of an approximately triangular mountainous region (Figure 1). Major drainage is approximately radial away from the central peaks, with Warm Springs Creek and Slate Creek draining northward to the Salmon River; Big Lake Creek, Big Boulder Creek, Little Boulder Creek, and Germania Creek draining eastward to the East Fork of the Salmon River; and Fourth of July Creek draining westward into the Salmon River within the Sawtooth Valley. Much of the entire region and all of the study area are within the boundaries of the Sawtooth National Recreation Area.

The Railroad Ridge diamicton is located on the east side of the White Cloud Peaks area on the the interfluves of the eastward-draining streams (Figure 1). Specifically, these locations are Railroad Ridge to the north of Jim Creek and Big Boulder Creek; the small ridge (informally called "the Spur") between Jim Creek and Big Boulder Creek above their confluence; Red Ridge between Big Boulder Creek and Little Boulder Creek; and the ridge (informally called "Trimline Ridge") comprising the southern interfluve of Little Boulder Creek. An associated deposit is found on the ridge (informally called "Agate Ridge") between Wickiup and Germania Creeks.

The study area is covered by six United States Geological Survey 7.5 minute topographic quadrangle maps: (1) Livingston Creek, (2)

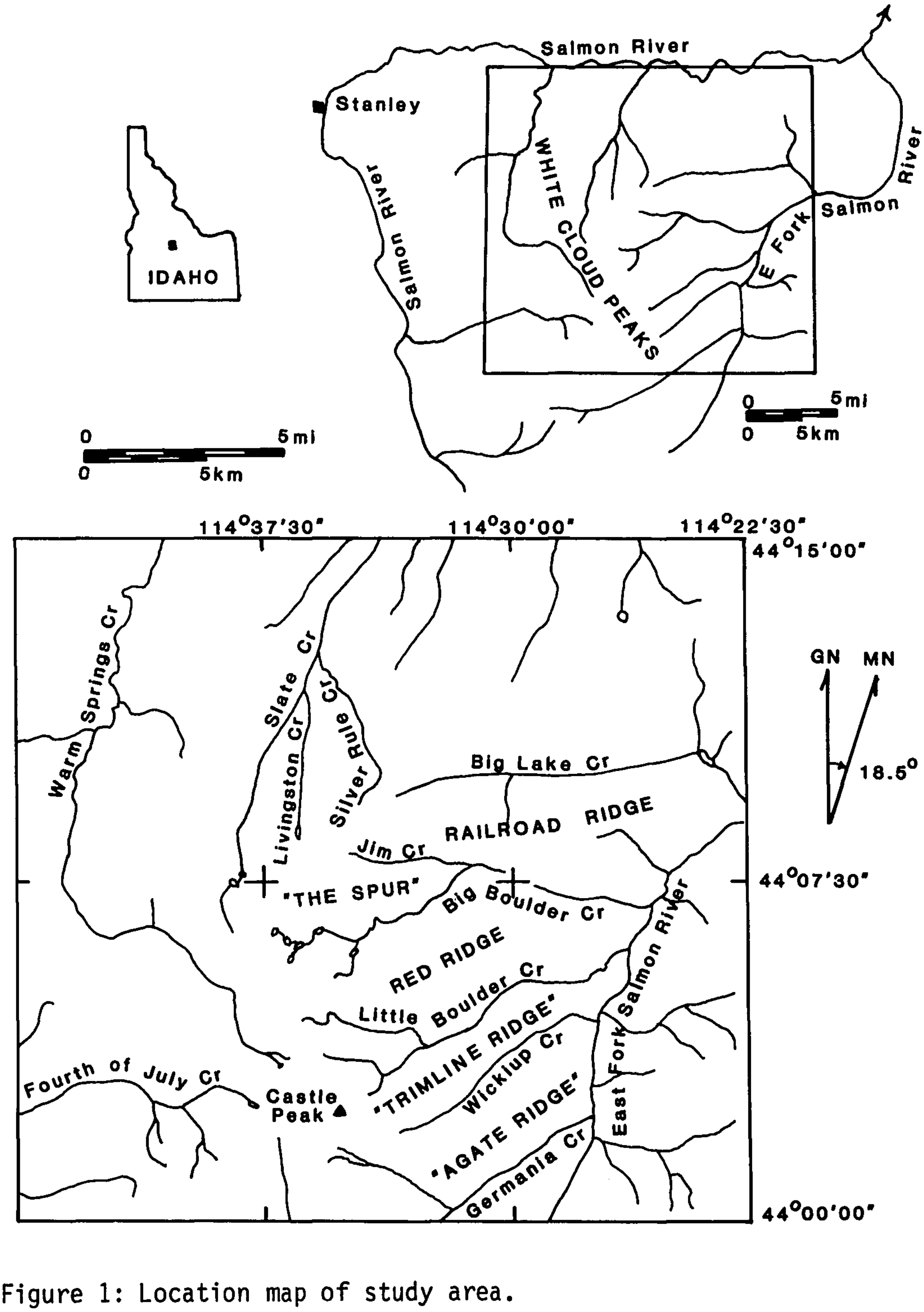

Figure 1: Location map of study area.

Potoman Peak, (3) Boulder Chain Lakes, (4) Bowery Creek, (5) Robinson Bar, and (6) Washington Peak. These are all included on the Challis 1:250,000 quadrangle map.

2.2 BEDROCK GEOLOGY

The bedrock of the study area can be divided into three major rock types: an intrusive quartz monzonite stock, regionally metamorphosed Paleozoic sedimentary rocks, and the extrusive Challis Volcanics. The geology of the region is mapped and discussed extensively in Ross (1937) and more recent small-scale mapping has been done by Seeland (unpubl.) in conjunction with the production of the U.S. Geological Survey Open File Report, Mineral Resources of the Eastern Part of the Sawtooth National Recreation Area, Custer and Blaine Counties, Idaho (Tshanz, et al., 1974). A generalized bedrock map of the central peaks region is shown in Figure 2.

The oldest rocks in the study area are Paleozoic metasediments. These are divided into two formations, the Mississippian Pole Creek Formation and the Permian Wood River Formation. The Pole Creek Formation, formerly known as the Milligan Formation (Warren Hobbs, 1979, oral commun.), is typically a black, carbonaceous argillite locally interbedded with impure quartzites and limestones. In the vicinity of the White Cloud stock these rocks are regionally metamorphosed, resulting in bleaching of the limestone beds and formation of secondary metamorphic minerals. The overlying Wood River Formation is thrust unconformably over the Pole Creek Formation in the area of Railroad Ridge (John Bachelder, 1979, oral commun.), although at its type section, the Wood River Formation conformably overlies the Pole Creek Formation. The lithology of the Wood River Formation consists of an argillaceous quartzite with impure limestone beds;

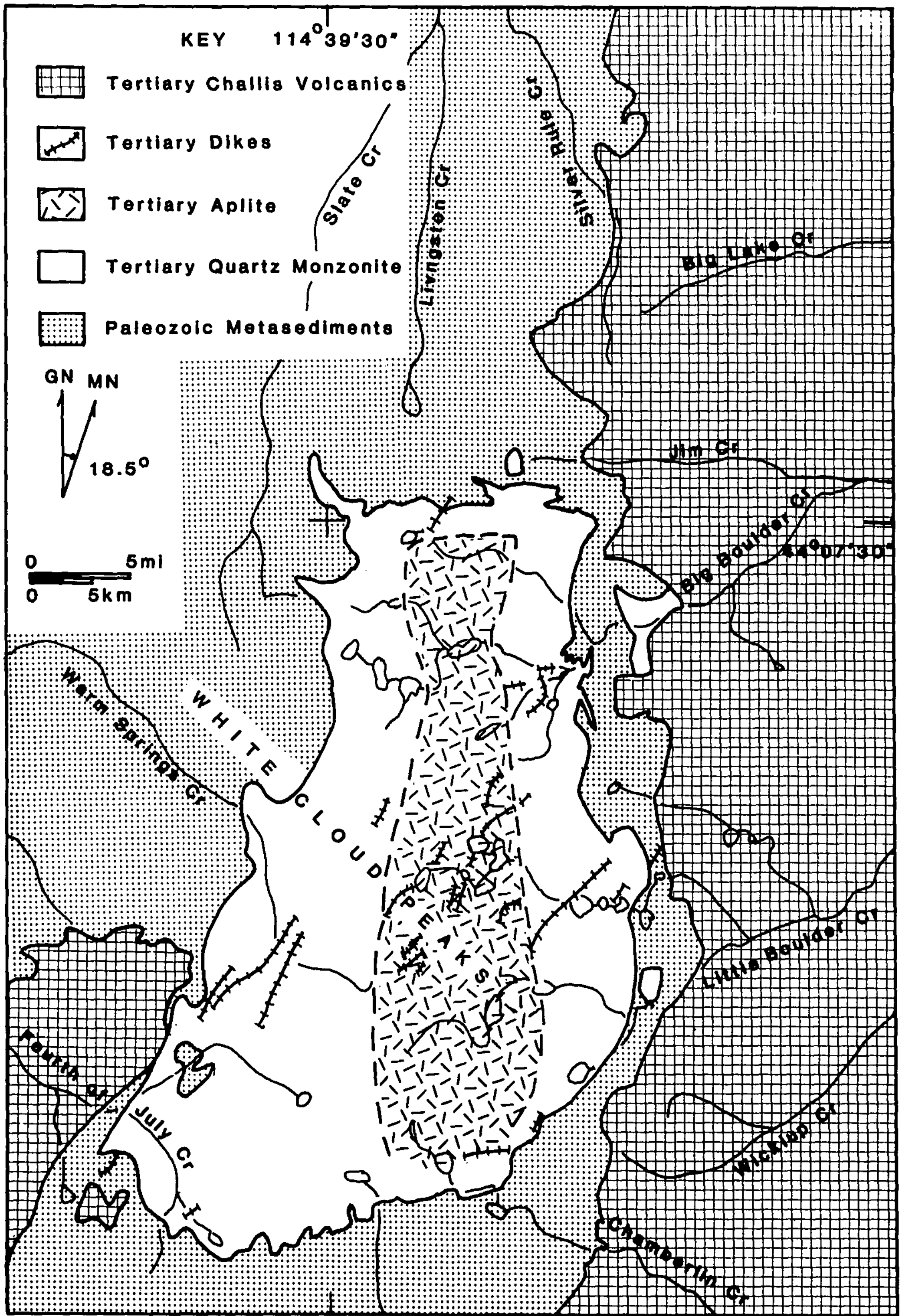

Figure 2: Generalized bedrock geology of the White Cloud Peaks area (after Ross, 1937; Seeland, unpubl.; and Tshanz et al., 1974).

however, regional metamorphism has significantly altered the appearance of the original sedimentary rocks, in large part by the conversion of the limestone beds into calcsilicates.

The White Cloud stock is a composite body of quartz monzonite related to the emplacement of the larger Idaho batholith during the middle to late Cretaceous (Bennett, 1976). This stock and the adjacent metasediments form the highest areas of the White Cloud Peaks. The central core of the stock is composed of leucocratic quartz monzonite, or aplite, and is surrounded by older, coarser quartz monzonite which is coarse-grained, gray to pink, and locally porphyritic. The aplite extends from about 4000 feet (1219 m) south of the Livingston Mine and Tin Cup Lake, skirting Big Boulder Lakes and the east side of Walker Lake, southward through Boulder Chain Lakes and Born Lakes, to the southernmost end of the stock (John Balla, 1981, oral commun.). At the margins of the stock, aplite dikes are intruded into the quartz monzonite and adjacent Paleozoic rocks. Biotite andesite dike swarms are also intruded into the stock (Ross, 1937).

The Tertiary extrusive rocks of south-central Idaho are known as the Challis Volcanics, and are assigned an Eocene age (Armstrong, 1978). These volcanics are composed of several different lithologies, four of which are extensively exposed in the study area: the Germer Tuffaceous Member, the Yankee Fork Rhyolite Member, a latite-andesite, and a basalt. These rocks were extruded onto an eroded land surface and thus vary extensively in thickness. There are also large variations in composition between these complexly-interbedded units (Ross, 1937).

The distribution of the three major rock units over the study area has influenced the geomorphology extensively. The resistant stock occupies the central highlands and is surrounded by a narrow belt of highly metamorphosed Paleozoics, which form high peaks as well as lower ridge lines. To the northeast, east, south, and southwest of the Paleozoics, the Challis Volcanics are the predominant bedrock, deposited on the eroded surface of less-metamorphosed Paleozoics.

2.3 QUATERNARY GEOLOGY

Extensive modification of the White Cloud Peaks landscape has been accomplished by a number of Quaternary geomorphic processes. Chief among these is glaciation; however, stream action, periglacial reworking, and mass movement, in the form of landslides and talus fall, are also important influences. Ross (1937) identified two glacial episodes, tentatively correlating them with the Nebraskan and Wisconsinan Glaciations of the mid-continent. The deposition of the Railroad Ridge diamicton he attributed to the Nebraskan Glaciation. The Wisconsinan Glaciation was responsible for the features associated with valley glaciation, including cirques, aretes, tarn lakes, U-shaped valleys, and numerous morainal deposits, now highly modified by subsequent fluvial action. Later work (Williams, 1961) in the nearby Stanley Basin area indicates three distinct periods of glaciation. The most extensive of these are correlated to the Pinedale and Bull Lake Glaciations of Blackwelder (1915) on the basis of position and degree of morainal weathering. Small moraines in the cirques are attributed to neoglacial activity. The Bull Lake Glaciation in the Stanley Basin involved two advances separated by a recession, as is found at the type section of the Bull Lake deposits. Williams also postulates an older glaciation based on the high elevation and extreme weathering of bouldery deposits in some areas of the Stanley Basin. This he compares to the Buffalo Glaciation (Blackwelder, 1915; Mears, 1974), although he is reluctant to assign either an age or origin to the sparse deposits.

In the White Cloud Peaks region, assignment of moraines to the Pinedale and Bull Lake Glaciations on the basis of morphology alone is impossible due to the scarcity of well-preserved morainic deposits. Zigmont (1982) suggests that the lack of mappable moraines may be due to one or both of two reasons: 1) nondeposition due to rapid ice retreat; and 2) post-glacial landform modification by stream action, landslides, etc. Although not pursued by Zigmont, further analysis of the relative positions of landslide escarpments, landslide debris, and glacial deposits could possibly provide a framework for a morphostratigraphic sequence in the region. Zigmont identified one major glacial episode and presented evidence for one possible earlier glaciation.

The latest major glaciation left extensive valley-floor deposits and moraines along the steep-sided canyon walls (Zigmont, 1982) (Figure 3). During field work for this study, moraines of the latest valley glaciation which were not mapped by Zigmont were noted (Figure 3), however these do not change the ice limits of the latest glaciation.

Elevated boulder deposits are found up to 1000 feet (305 m) above the valley floors yet below the ridgetops, above Zigmont's (1982) reconstructed ice margins. In Big Boulder Creek, Zigmont correlates these high deposits to the Railroad Ridge diamicton in a possible "pre-canyon" glaciation or slumping of adjacent ridges capped by diamicton, rather than attributing the elevated deposits to an earlier valley glaciation. He bases this contention on the following

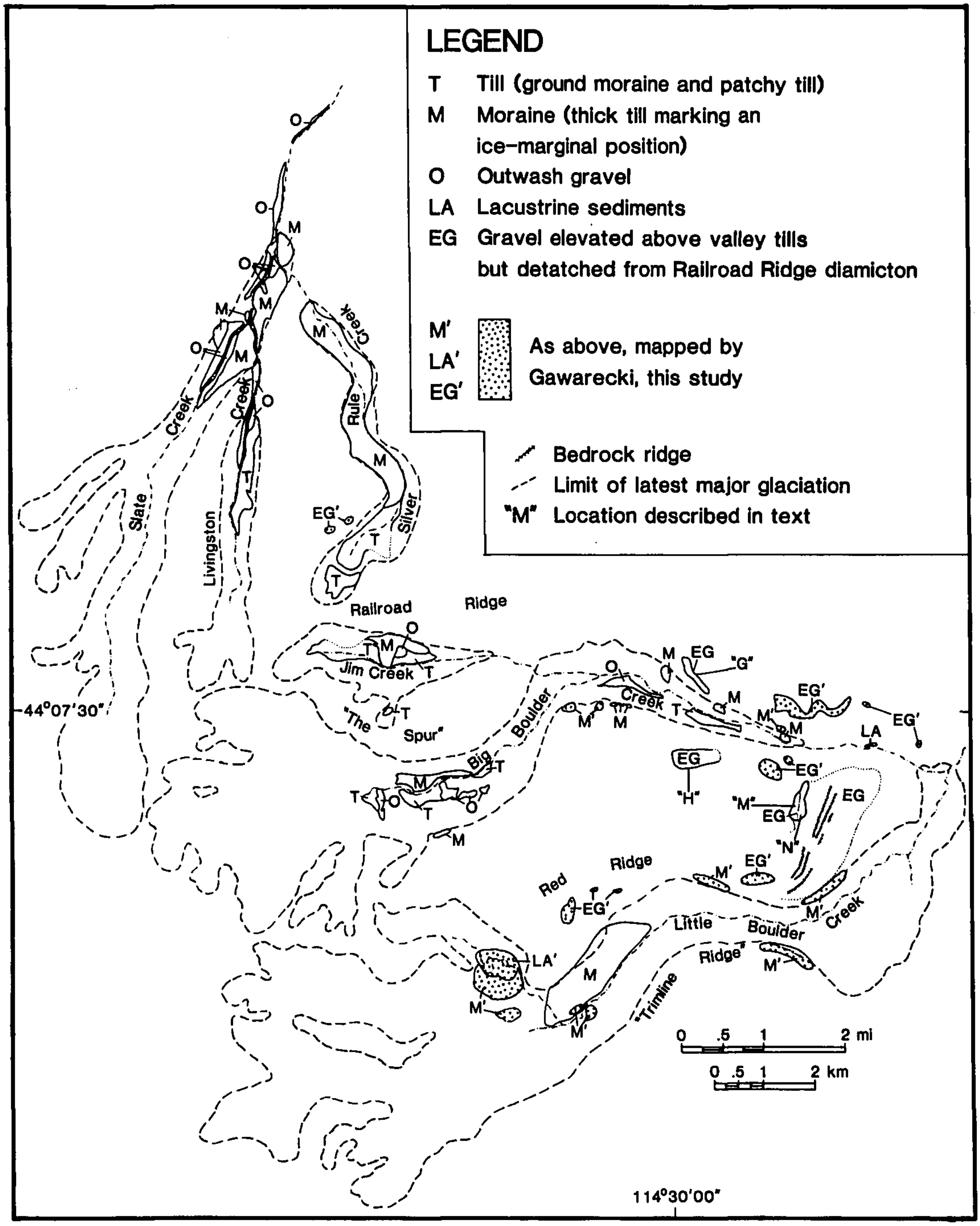

Figure 3: Glacial limits and moraine positions of the northeastern White Cloud Peaks area (modified from Zigmont, 1982).

arguments: 1) that the glacial profile from the higher deposits (Figure 3: G, H) to his mapped limit of glaciation is too steep for the calculated basal shear; and 2) that the depth of ice in Big Boulder Creek needed to source these deposits is infeasible based on the catchment area. Both of these conclusions, however, may be invalid for the following reasons: 1) there are other gravel deposits high along the valley walls downstream of G and H (Figure 3), one of which Zigmont sampled but did not map, thus the profile he postulates could be erroneous; and 2) the valley floor would have been at a significantly higher elevation during an early glaciation, so an extreme thickness of ice is not required. Further evidence for an early valley glaciation is found in the moraine ridges (Figure 3: M, N) mapped by Zigmont (1982) at high elevations near the mouth of Little Boulder Creek. These correspond to the high moraines in Big Boulder Creek on the basis of altitude. The "bedrock ridges" below these moraine ridges (Figure 3) need not be due to shaping of the soft but brittle Challis Volcanics, as Zigmont has postulated; rather they may be abandoned marginal drainage channels.

Evidence for a possible very old third glacial (?) episode is found in the form of isolated boulders along the East Fork of the Salmon River up to 1600 feet (487 m) above the river and downstream of Jimmy Smith Lake in Big Lake Creek. Investigation of boulders at the latter location indicates that they are erratics up to several feet in diameter. Extensive research of these erratics has not been undertaken.

Glacial outwash terraces are poorly preserved in the study area, although they are extensive in the valley of the East Fork of the Salmon River. Ross (1937) describes terrace remnants at elevations of 100, 200, 300 and 1500 feet (30, 61, 91, and 457 m) above the current river. To the north along the Salmon River, Ross recognizes terraces up to 1000 feet (305 m) above stream level. There has been no attempt to correlate the lower terraces in this area with the glacial episodes, although Ross (unpubl.) believes the highest terraces are related to the deposition of the Railroad Ridge diamicton, due to the presence of granitic boulders.

Postglacial stream action in the lower reaches of Big Boulder and Little Boulder Creeks has deeply entrenched glacial deposits and underlying bedrock. This has caused the post-Wisconsinan cross-sectional profile of the lower valleys to be extensively modified and has smoothed the morphology of the valley-bottom till deposits, obscuring their original form (Zigmont, 1982). Small Holocene alluvial fans have formed at the base of valley walls.

Locally, landslides are a major factor for landform modification. In the study area landslide deposits are common, although none appear recent. The Challis Volcanics, in particular the Germer Tuffaceous Member and Yankee Fork Rhyolite Member, are prone to failure on steep slopes (Tshanz et al., 1974). Landslides are relatively rare in the rocks of the White Cloud stock and the Paleozoic metasediments, therefore these units hold steep slopes and retain the U-shaped profile of the glaciated valleys. Extensive landsliding in the glaciated valleys carved into the Challis Volcanics has in many cases destroyed their former U-shaped profiles. It is likely that most of the slope failures occurred after glacial retreat left the oversteepened slopes unsupported. In some instances, subsequent readvance or a later glacial episode removed the debris. After the final glacial retreat, massive landsliding occurred into Jim Creek from "the Spur;" this left much hummocky debris in the valley, obscuring the glacial landforms and the original valley profile. Revegetation and extensive downcutting of this deposit by Jim Creek indicate that it is quite old, probably late Pleistocene or early Holocene in age.

3 PREVIOUS WORK ON THE RAILROAD RIDGE DIAMICTON AND SIMILAR DEPOSITS

Speculation regarding the origins of the Railroad Ridge diamicton has focused of its composition, its ridgetop position and its association with an ancient erosion surface. Ross (1929), the first to investigate the deposit, described it as being an unsorted, poorly rounded, uncemented but compacted mass containing large erratic boulders of granitic rock. At the base of the deposit he found smaller clasts of the local bedrock, Paleozoic metasediments, but was unable to determine whether or not this bedrock was polished or grooved.

Ross (1929) reasoned that the deposit must be of early Pleistocene age based on:

1. its relatively fresh appearance and unconsolidated character;
2. its deposition on a late Tertiary erosion surface; and
3. its ridgetop position implying deposition prior to the present erosion cycle.

The deposit's pre-Wisconsinan age is indicated by the erosion of assumed Wisconsinan age cirque headwalls into the deposit in the drainages of Silver Rule and Jim Creeks. In a later work, Ross (1937) tentatively assigned a Nebraskan age to the deposit. Seeland (unpubl.) has presented clast-weathering ratios which provide further evidence for the relative antiquity of the Railroad ridge diamicton. The granitic boulders of the Railroad Ridge diamicton are 41% fresh, 45% slighty weathered, and 14% weathered. This compares to the granitic boulders of the valley glacial deposits which are 86% fresh, 14% slighty weathered, and 0% weathered.

According to Ross (1929; 1937), the presence of extremely large boulders in the Railroad Ridge diamicton requires a depositional agent with sufficient competence to transport large boulders up to several miles from the nearest possible source. Ross considered a torrential stream an unlikely mechanism in that the potential catchment area is small and that such a stream would not selectively erode only granitic boulders. On the other hand, he noted that glaciers are fully competent to carry large boulders. Glacial deposits are typically unsorted, and glaciers selectively erode their source areas. On this basis, Ross (1929) concluded that the deposit is of glacial origin. He explained the flat morphology, atypical of glacial ground moraine, as the result of subsequent smoothing by water action.

The Railroad Ridge diamicton is one of a number of similar deposits which have been tentatively assigned an early Pleistocene age and glacial origin. A list of nearly 100 such deposits has been compiled by Richmond (1957) from the Rocky Mountain states of New Mexico, Colorado, Wyoming, Idaho, and Utah. Richmond (1957) assigned a "pre-Wisconsin" age to these deposits. The deposits tend to share certain characteristics (Richmond, 1957) which also appear in the Railroad Ridge diamicton (Ross, 1929; Ross, 1937; Ross, unpubl.).

Physiographically, the deposits described by Richmond (1957) tend to occur as isolated exposures, are generally sheetlike in form, and lack morainal topography. Ross (1937, p. 95) described patches of the Railroad Ridge diamicton as having "large lateral dimensions in proportion to their thickness" and being "flat and smooth on top."

The pre-Wisconsin deposits may lie high in the canyons and lap onto the divides, or they may cap the interfluves (Richmond, 1957). The Railroad Ridge diamicton falls in the latter catagory. The position of the ridgetop deposits suggests that they predate the erosion of the modern canyons.

Physically, the pre-Wisconsin deposits "consist of unsorted, unsized, non-bedded, bouldery material" (Richmond, 1957, p. 240). The diamicton on Railroad Ridge and nearby ridges is "composed of poorly sorted . . . gravel that ranges from coarse sand to boulders more than 10 feet (3 m) long" (Ross, 1937, p. 70). The ridgetop deposits are generally finer-grained, more compact, more strongly jointed than younger tills, and commonly possess a thick, mature soil profile (Richmond, 1957). The Railroad Ridge diamicton is compact enough to hold a steep slope in fresh cuts but shows no sign of cementation (Ross 1929; 1937).

An example of a ridgetop deposit similar to the Railroad Ridge diamicton is Blackwelder's (1931a) McGee tilloid, the earliest of four apparent glacial deposits of the east side of the Sierra Nevada. His description could be of the Railroad Ridge diamicton:

> "On the high ridge west of McGee Peak several thick patches of a deposit strongly resembling till and consisting largely of granite debris rest upon a foundation of Paleozoic slate and marble" (Blackwelder, 1931a, p. 902).

Blackwelder (1931a) also reports that granitic erratics, many exceeding 10 feet (3 m) in length, have been transported up to 3.5 miles (5.6 km) from their source; large quartz monzonite boulders in the Railroad Ridge diamicton have also been found an equivalent distance from the stock. It is interesting to note that the McGee tilloid is well-exposed on the east side of the Sierra Nevada, similarly the the Railroad Ridge diamicton lies on the east side of the White Cloud Peaks; both are only poorly, if at all, exposed on the west side of their respective ranges. Although evidence is sparse, Blackwelder (1931a) concluded that the McGee tilloid must be a deposit of glacial origin, just as Ross (1929; 1937) felt that the Railroad Ridge diamicton was a till.

There are a number of deposits in central Idaho which have been described by Ross (1929; unpubl.) as bearing striking similarities to the Railroad Ridge diamicton. These deposits are found in the following locations:

1. high on the west side of Loon Creek near Stanley, Custer County;

2. in placer pits near Burgdorf, Valley County;

3. along the upper reaches of Little Wood River, Blaine County; and

4. on the divide between Stanley and Kelley Creeks, north of Stanley.

The deposits of Loon Creek and Little Wood River are composed of a poorly sorted matrix and highly weathered boulders, and are thought to be remnants of ancient moraines (Ross, unpubl.). The Burgdorf exposure has been described by Capps (1940) as consisting predominantly of quartzite and disintegrated granitic boulders, which are present several hundred feet above the stream as well as on top of the surrounding ridges. Williams (1961) regards highly-weathered boulders exposed in old placer workings between Stanley and Kelley

Creeks as correlatable with the Buffalo drift. All of these locations are close to some of the tallest peaks in Idaho (Ross, 1929).

Geologic maps of the White Clouds area have shown the position of the Railroad Ridge diamicton with varying detail and, because they do not all agree, with varying degrees of accuracy. Ross' (1937) geologic map, the first of the area, does not differentiate the ridgetop diamicton from high moraines along the valley walls; all are mapped as "glacial deposits." The open file map, "Geologic and Aeromagnetic Map of the Eastern Part of the Sawtooth National Recreation area," (Tshanz et al., 1974) maps the Railroad Ridge diamicton as "older gravel", and does not discriminate between the ridgetop diamicton and later valley-fill or alluvial deposits, some of which are also mapped as "older gravel." Preliminary geologic maps showing detailed surficial geology at a scale of 1:24,000 that have been produced by Seeland (unpubl.) in conjunction with the Sawtooth NRA Project (Tshanz et al., 1974) also show the "older gravels;" these are restricted to exposures of the Railroad Ridge diamicton but are inaccurate regarding the extent of the deposit. The 7.5 minute quadrangles mapped by Seeland (unpubl.) are Boulder Chain Lakes, Livingston Creek, Horton Peak, Robinson Bar, and Washington Peak.

4 FIELD INVESTIGATION

4.1 DIAMICTON CHARACTERISTICS AND EXTENT

The first objective of the research was to map the extent, thickness, and variations (i.e., typical diamicton, isolated boulders, etc., see below) of the Railroad Ridge diamicton. It was mapped and sampled in the field in July and August of 1979. United States Geological Survey 7.5 minute quadrangles were used as base maps. Aerial photograph interpretation supplemented field observations. The following mapping units were used (Plate 1):

1. "typical" diamicton;
2. isolated boulders;
3. dissected diamicton;
4. colluviated diamicton;
5. landslide-transported diamicton; and
6. associated deposits.

The Railroad Ridge diamicton varies in character from area to area (Plate 1). These variations are reflected in the mapping units used. The most common, and therefore considered "typical" deposit of the Railroad Ridge diamicton is that of quartz monzonite boulders in an unconsolidated matrix with a gently sloping ridgetop surface. This is the appearance of the main body of diamicton on Railroad Ridge (Figure 4) and on the crests of ridges to the south.

Along the margins of the "typical" deposits are found the other manifestations of the diamicton. Isolated quartz monzonite boulders

Figure 4: Railroad Ridge, view east from Silver Rule cirque. Note the exposure of fresh diamicton in the lower right corner of the picture.

lying on bedrock are found in several locations (Plate 1: (1), (4), (11), (21), (22)). Their appearance near the diamicton limits where the deposit is thin suggests that any matrix originally deposited with these boulders has been eroded away. Areas of Railroad Ridge diamicton also exist where the smooth surface morphology of the "typical" diamicton has been modified by fluvial erosion (Plate 1: (13), (17)). Here, small consequent tributaries have dissected the diamicton and are apparently controlled by the original slope of the deposit's surface. Colluviated diamicton is found along the valley walls (Plate 1: (9), (15), (16)) where the deposit has sufficient thickness to form an erosional escarpment and contribute material to downslope movement. Post-depositional landslides have also contributed to the displacement of diamicton (Plate 1: (12), (18)). In all cases these slope failures have occurred in the underlying Challis Volcanics. Deposits which resemble the Railroad Ridge diamicton in either position or character but are lacking an attribute which otherwise would allow them to be classified in the first five catagories (with the exception of obvious valley tills) have been mapped as "associated deposits." This term encompasses possible talus deposits (Plate 1: (7), (8)), basaltic boulders on a basalt bedrock ridge (Plate 1: (23)), an unreachable but similar-appearing area (Plate 1: (10)), possible high valley till deposits (Plate 1: (5)) and possible mass- or ice-transported diamicton in the upper reaches of Big Lake Creek (Plate 1: (20)).

Extensive deposits of the Railroad Ridge diamicton occur on four major ridgetops in the study area (Plate 1). The northernmost of these deposits is on Railroad Ridge and extends from scattered isolated boulders on the western end above Crater Lake (Plate 1: (21)) 2.3 miles (3.7 km) east along the relatively flat ridgetop (Figure 4). The diamicton achieves an estimated thickness of about 300 feet (91 m) along the central part of the ridge. Quartz monzonite boulders isolated on bedrock are also found extending down onto the low divide between Silver Rule cirque and Big Lake Creek (Plate 1: (1)). Two isolated patches of "typical" diamicton are found along Big Lake Creek on the low ridges projecting northward into that canyon from Railroad Ridge (Plate 1: (2), (3)); another scatter of boulders on bedrock (Plate 1: (4)) marks the western extent of the diamicton on Railroad Ridge. Two small patches of typical diamicton are also found on the ridge between Silver Rule Creek and Livingston Creek (Plate 1: (6)). In addition, two small patches of diamicton, mapped as associated deposits (Plate 1: (5)) because they lie off of the crest of the ridge, were encountered. These may be old high valley till remnants of the Silver Rule Creek glacier predating the latest recent glaciation described by Zigmont (1982).

The distribution of the Railroad Ridge diamicton or an associated deposit is anomalous in the head of Big Lake Creek, northeast of the main body of the ridgetop deposit on Railroad Ridge. Along the north wall of the canyon, quartz monzonite boulders are found up to about 400 feet (122 m) above the stream (Plate 1: (19)). On the opposite side of the canyon, Challis Volcanics bedrock ridges are mantled with diamicton at elevations ranging from 8240 feet (2512 m) to 9080 feet (2768 m) (Plate 1: (2), (3), (4)), and there is much bouldery material in the small tributaries (Plate 1: (20)). This is the only area where the Railroad Ridge diamicton is found in a valley bottom, thus it is mapped as an "associated deposit."

The next small ridge to the south, informally called "the Spur", is largely capped by bouldery deposits. The westernmost end consists of a deposit of rounded granitic boulders, resembling a felsenmeer (Plate 1: (7)) and is mapped as an associated deposit. East of this, above adits of the Livingston Mine (Plate 1: (8)), clasts are talus derived from the predominantly metasedimentary outcrop to the south. Continuing eastward, the boulder lithology again changes to predominantly quartz monzonite and is probably derived from local outcrops along the narrow ridgeline. This western half of the deposit on "the Spur" extends for 1.5 miles (2.4 km) and was mapped as an associated deposit (Plate 1: (7), (8)). After an eroded gap of 0.25 mile (0.4 km), the deposit reappears (Plate 1: (16)) and attains its greatest thickness, 520 feet (158 m), with an appearence similar to the "typical" diamicton on Railroad Ridge. This section extends approximately 0.6 mile (1.0 km) eastward along "the Spur" and is cut off by a landslide escarpment and valley erosion on its northeast slopes (Plate 1: (9)). Below the escarpment, a large area of hummocky, landslide-transported diamicton is found (Plate 1: (18)). Within the escarpment, apparent layers or concentrations of large boulders and a subhorizontal brown zone were noted. The bouldery layers and brown zone were visible from Railroad Ridge. The 42-inch (106-cm) thick brown zone consisted of subhorizontal compacted layers of different colors beneath about 20 inches (51 cm) of layered colluvial material. This section is summarized in Figure 5.

To the south and east, the diamicton is found on Red Ridge. The westernmost deposit (Plate 1: (10)) is found at about 10,800 feet (3292 m) capping a high, flat-topped, isolated peak. This peak was not visited and therefore the exact nature of the deposit is unknown; however, with binoculars it appears to be composed of granitic bouldery rubble and is thus mapped as an associated deposit. Isolated quartz monzonite boulders on Paleozoic bedrock are found on a lower knob east of the high one, at 10,093 feet (3076 m) (Plate 1: (11)). The main body of "typical" diamicton on Red Ridge begins in the low gap through which the trail from Big Boulder Creek to Spring Basin passes. The ridgetop distribution forms a crude upside-down T-shape with the top bar of the T running parallel to Little Boulder Creek approximately 2.3 miles (3.7 km) and the stem of the T running north 1.3 miles (2.1 km). This deposit strongly resembles the other "typical" ridgetop deposits of Railroad Ridge and "the Spur" and probably attains a thickness of 400 feet (122 m). West of the T's stem is a large hummocky area (Plate 1: (12)) covered with boulders; this is a landslide of Challis Volcanics bedrock which was originally covered with diamicton. East of the T's stem is a large area of dissected diamicton (Plate 1: (13)) extending about 1.7 miles (2.7 km)

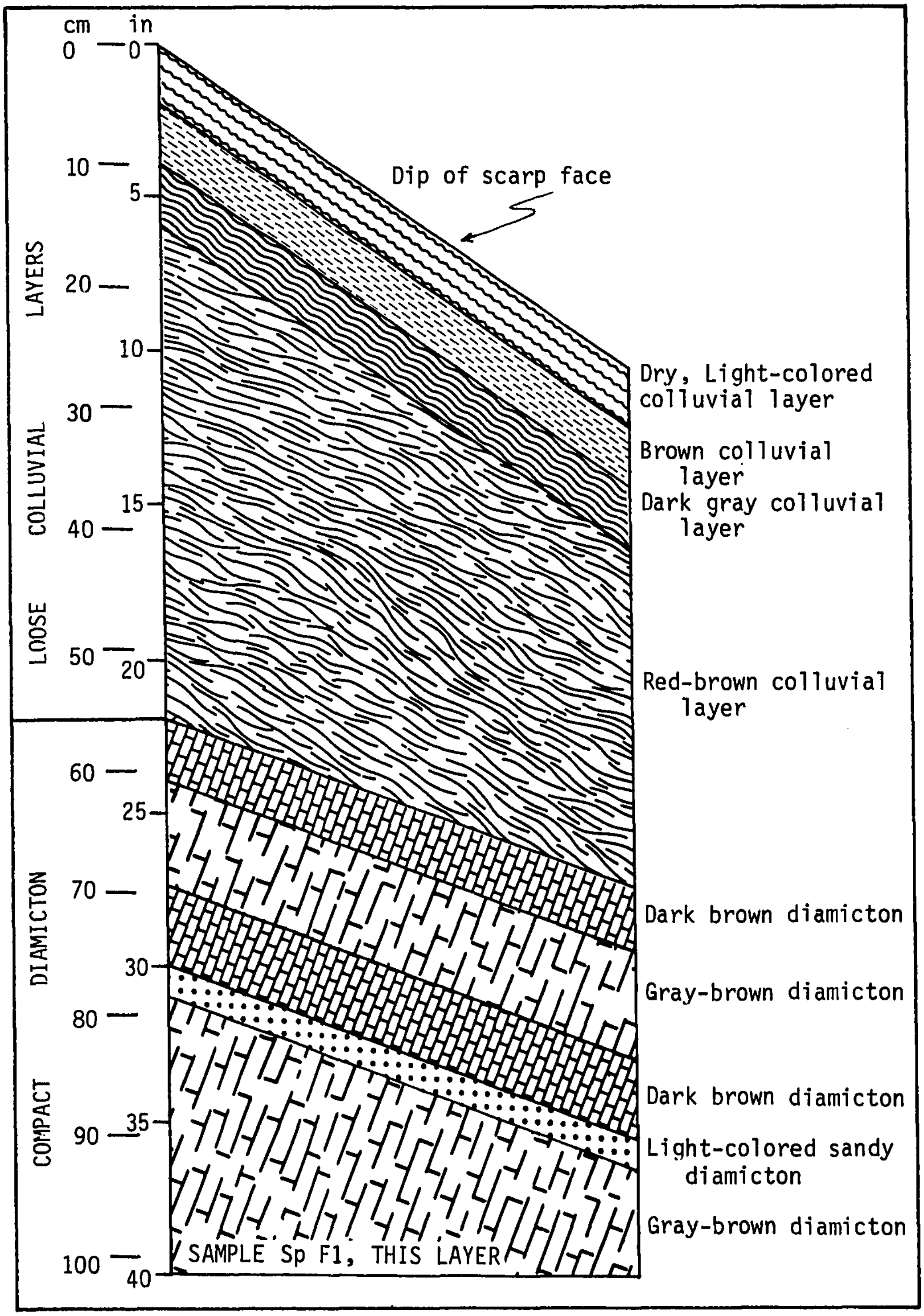

Figure 5: Sketch of brown zone in landslide escarpment.

north and 1.5 miles (2.4 km) east. Erosion has left isolated boulders on one small ridge (Plate 1: (22)) and has removed the diamicton from another small bedrock ridge entirely (Plate 1: (14)). The interfluves of the southern small tributaries remain covered with an unknown thickness of diamicton. This area has well-developed consequent parallel drainage, not unlike the area on Railroad Ridge near sample location RRR K (Plate 1: (17)).

The final major ridgetop exposure of "typical" diamicton is on the divide between Little Boulder and Wickiup Creeks, informally called "Trimline Ridge." The western boundary is well-defined, ending at 8800 feet (2682 m) against Challis Volcanics bedrock. Everywhere along flanks of the ridge and at the eastern end, the diamicton colluviates downslope where it mixes with valley till. This material is mapped as colluviated diamicton. The diamicton on "Trimline Ridge" extends northeast 2.1 miles (3.4 km).

The ridge to the south of "Trimline Ridge," informally called "Agate Ridge," was mapped by Seeland (unpubl.) as covered by older gravels. However, there was no evidence found of any deposit resembling the Railroad Ridge diamicton at this location. "Agate Ridge" retains remnants of the post-Challis erosion surface, developed on black basalt. In one location (Plate 1: (23)) numerous black basalt boulders were found on the ridgetop. It is unknown whether these boulders are genetically related to the other ridgetop diamictons or derived from weathering of the underlying bedrock, thus this area was mapped as an associated deposit. The lack of transported quartz monzonite boulders supports a weathering origin. More detailed reconnaissance work is recommended for the areas to the west and south of "Trimline" and "Agate Ridges," as access problems limited investigation of these areas.

There is no evidence that the Railroad Ridge diamicton extended further eastward than its current limits on Railroad and Red Ridges. The boulder deposits on these ridges end abruptly. On Challis Volcanics bedrock of Railroad Ridge a scattering of stream-worn erratics (no quartz monzonite clasts) is found beyond the limit of the diamicton (Plate 1: (RRR N)). The relationship of these erratics to the Railroad Ridge diamicton is not known. The former extent of the diamicton in other areas is unknown as erosion has likely removed much material, especially in the vicinity of "Trimline Ridge."

4.2 SAMPLE SITES

The Railroad Ridge diamicton was sampled for provenance investigations using a non-random selective pattern at intervals adequate to represent the mapped area of diamicton within the limit of available time. Sample sites are located on Plate 1. At most sample sites, the lithologies of 25 surface boulders were determined, with "boulder" defined as any rock larger than 6 inches (15 cm) medium diameter. In addition, 50 or 100 pebbles were excavated from 12- to 18-inch (30 to 46 cm) deep dug pits and the lithology of each pebble determined. "Pebble" was defined as any clast one to three inches (2.5 to 7.6 cm) in diameter. Finally, a 100 to 500 gram matrix sample was taken from the bottom of each pit for heavy mineral analysis. Not all sample sites included all three types of provenance samples. On Railroad Ridge, RRR G lacked boulders at the surface so only pebble lithologies and heavy mineral species were analyzed. RRR N consisted of relict stream cobbles on a bedrock surface and therefore only exotic boulder lithologies were determined. RRR R and RRR S were dug from a fresh cut in the diamicton, hence there were no surface boulders for lithology determinations. On the Spur pit Sp E1 yielded no pebbles from between tightly wedged boulders. Samples Sp F1 and Sp G1 were from a fresh landslide escarpment in the deposit and no boulder lithology determinations were possible. On Red Ridge, Red B2L was in colluvial material of weathered Challis Volcanics bedrock and Red B2U was in overlying colluviating diamicton, and neither boulder nor pebble lithology determinations were possible.

Besides areas of known Railroad Ridge diamicton, samples were also taken from associated deposits or other deposits for comparison. In addition to those mentioned above (RRR N, Red B2L, and Red B2U), others are:

1. RRR O, from a high deposit of a possible early valley glaciation;

2. RRR P, a probable early valley glacial deposit;

3. Sp A1, resembling a felsenmeer; and

4. Sp B1 and Sp C1, apparently fresh colluvial material, possibly incorporating older gravels as well.

Five of the matrix samples were also analyzed for grain size distribution. These were samples taken from fresh exposures to minimize the effects of soil weathering processes. Three samples were from the Silver Rule cirque (RRR C, RRR R, RRR S) and two samples were from the landslide escarpment on "the Spur" (Sp F1, Sp G1). Sp G1 was from typical gray diamicton and Sp F1 was from the brown zone which proved to lack clasts larger than cobble size. Pebbles in this zone were highly weathered.

4.3 DIAMICTON MORPHOLOGY

The thickness of the deposit varies from a thin veneer of boulders over bedrock (Plate 1: (1), (4), (11), (21), (22)) to an estimated thickness of greater than 500 feet (152 m) (Plate 1: sample site Sp E1). In general, the diamicton is thin at its boundary near the stock and thickens quickly to a maximum of about 520 feet (158 m) on "the Spur." In some places the diamicton thickness was difficult to estimate owing to lack of visible contacts with underlying bedrock. The thickest part of the diamicton is found on the ridges along a band approximately parallel with the axis of the White Cloud Peaks (Figure 1).

In many areas, the Railroad Ridge diamicton has a relatively flat surface. This surface often has a noticeable slope, which was measured, orthogonal to contour lines, from the 7.5 minute topographic maps. The transects are plotted on Figure 6. The slope of the deposit surface along the main part of Railroad Ridge is 5.7° eastward, (Figure 6: A to A') in comparison to the bedrock surface to the east which has a slope of about 3.0° (Figure 6: B to B'). The surface of the diamicton near the head of Big Lake Creek, dissected by parallel drainage, slopes 7.4° northeastward (Figure 6: C to C'). The easternmost portion of diamicton on the Spur has a surface which slopes to the east at 4.1° with the underlying bedrock sloping at approximately 9° (Figure 6: D to D'). On the westernmost knob of Red Ridge at 10,800 feet (3292 m), the diamicton slopes 11.3° to the east (Figure 6: E to E'). The main body of diamicton on Red Ridge slopes

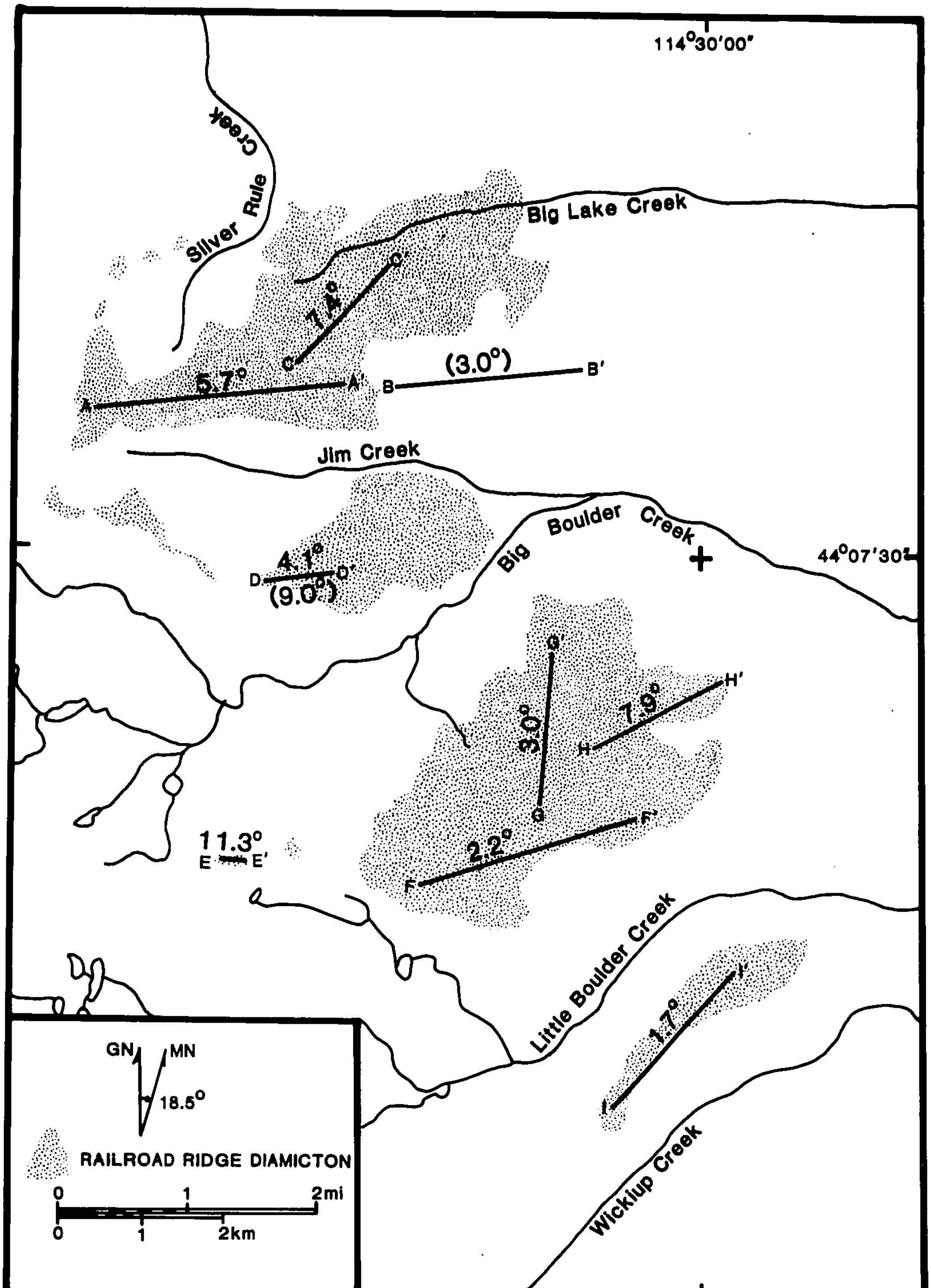

Figure 6: Transects and measured slopes of the Railroad Ridge diamicton and bedrock surfaces. Bedrock slopes are in parentheses.

2.2° northeastward (Figure 6: F to F') with a slope of 3.0° along the north-trending leg (Figure 6: G to G'). The eastern section of the diamicton on Red Ridge, dissected by parallel drainage, slopes 7.9° to the northeast (Figure 6: H to H') the exposure of diamicton on Trimline Ridge has a slope of about 1.7° to the northeast (Figure 6: I to I').

5 LABORATORY METHODS

5.1 SIZE ANALYSES

Size analyses were performed on five unweathered matrix samples. These five samples, RRR C, RRR R, RRR S, Sp Fl, and Sp Gl, were excavated from relatively recent erosional scarp faces, and thus have not been affected by processes of soil formation.

The size analyses were performed in the following manner:

1. Mix 25 g of sample with water and add 20 ml of 50 g/l peptizer solution.

2. Agitate for 20 minutes to disperse clay flocs.

3. Wet sieve the sample through a 4 phi sieve so that the fine fraction is washed into a 1000 ml cylinder (phi = $-\log_2 d$, where d is the grain diameter in millimeters).

4. Wash the coarse fraction (larger than 4 phi) into a beaker, dry in an oven, and dessicate.

5. Brush the coarse fraction into the top of a nest of sieves. In this study the following sieve sizes were used: from -2.25 phi to -1.25 phi in 0.5 phi increments and from -1.0 phi to 4.0 phi in 0.5 phi increments.

6. Shake the sample on the sieve shaker for 10 minutes.

7. Weigh and record the size fraction remaining on each sieve.

8. Pour the pan fraction (smaller than 4 phi) into the cylinder; bring the water volume to 1000 ml.

9. Shake cylinder vigorously to mix the suspension.

10. Using Stoke's settling laws at 25°C, pipette 20 ml of the suspension at the stated depth for each size fraction (Table 1).

11. Empty each 20 ml aliquot into a preweighed beaker and follow by a rinse with distilled water.

12. Dry the samples in an oven, dessicate, and weigh them.

13. The weight of each size fraction is found by subtracting the beaker weight plus 0.01 g (dispersant weight) from the beaker and fraction weight, the difference is the 20 ml fraction weight, which is multiplied by 50, yielding units of g/l of sediment. Each number, now representing the "finer than" size fraction is subtracted from the previous fraction; the result is the weight of each phi size.

SIZE FINER THAN	DEPTH	TIME
4 phi	20	0:00:20
5 phi	20	0:03:22
6 phi	10	0:06:45
7 phi	10	0:27:01
8 phi	10	1:48:04
9 phi	10	7:12:--
10 phi	5	14:25:--

Table 1: Pipette schedule for fine fraction, based on Stoke's Laws at 25° C.

Analysis of the grain size data yielded Folk and Ward's (1957) statistical determinations of mean, standard deviation, skewness, and kurtosis, using the equations given in Table 2.

Mean	M=(phi 16 + phi 50 + phi 84)/3
Standard Deviation	Sd=(phi 84 - phi 16)/4 + (phi 95 - phi 5)/6.6
Skewness	Sk=(phi 16 + phi 84 - 2 phi 50)/ (2(phi 84 - phi 16)) + (phi 5 + phi 95 - 2 phi 50)/(2(phi 95 - phi 5))
Kurtosis	K=(phi 95 - phi 5)/(2.44(phi 75 - phi 25))

(Note: phi X is X cumulative percentage in phi grain size units)

Table 2: Formulas for size analysis statistical parameters (after Folk and Ward, 1957).

5.2 PROVENANCE OF MATRIX SAMPLES

A provenance study was carried out on 38 matrix samples from 18-inch (46-cm) deep dug pits in the Railroad Ridge diamicton. The 3 phi size fraction of each sample received the following treatments prior to 300-grain heavy mineral determinations from slides.

A. Pretreatment for iron and manganese coatings:

1. Add to the sample 40 ml of .3 M sodium citrate and 5 ml of 1 M sodium bicarbonate.

2. Bring the mixture to 80°C in a water bath.

3. Add 1 g of solid sodium dithionite.

4. Stir constantly for 1 minute, then occasionally for a total of 15 minutes.

5. Rinse the sample with water, dry in an oven, and dessicate.

B. Heavy liquid separation:

1. Prepare a heavy liquid of specific gravity (s.g.) 2.75 by diluting tetrabromoethane ($CHBr_2$-$CHBr_2$, s.g. 2.96) with dimethyl formide ([(HCON $(CH_3)_2$], s.g. 0.95).

2. For each pretreated sample, fit surgical tubing closed with a clamp over the end of a funnel.

3. Pour heavy liquid into the funnel until half full; add the sample.

4. Stir with a glass rod until all the mineral grains are wetted.

5. Let the sample sit in the heavy liquid at least 24 hours, stirring occasionally, in order for the grains of specific gravity greater than 2.75 to sink.

6. Partially drain the sample into a filtered funnel so that the heavy minerals go into the filter and the lighter minerals remain behind.

7. Repeatedly rinse the heavy fraction with acetone to remove the heavy liquids. The sample is now ready to be mounted on a slide for provenance determinations.

6 RESULTS

6.1 SIZE ANALYSES

Size analyses were performed on the finer than -2.25 phi fraction of five matrix samples taken from fresh, eroded cuts within the body of the diamicton (Plate 1: RRR C, RRR R, RRR S, Sp F1, and Sp G1). The raw data is presented in Appendix 1. Figure 7 is a plot of the size analysis data. The size distributions for the five samples are similar, despite a relatively wide separation of the sample sites.

The Folk and Ward (1957) statistical parameters are given for each of the five matrix samples in Table 3. These were calculated using the equations given in Table 2 applied to the cumulative totals of the smaller than -2.25 phi (granule to clay) size fractions.

STATISTICAL PARAMETERS	RRR C	RRR R	RRR S	Sp F1	Sp G1
Mean	2.35	2.15	1.30	1.68	1.95
Stnd. Dev.	2.93	3.18	2.98	3.10	2.73
Skewness	0.053	0.13	0.31	0.35	0.26
Kurtosis	0.86	0.75	0.86	0.93	1.08

Table 3: Statistical parameters for five matrix samples.

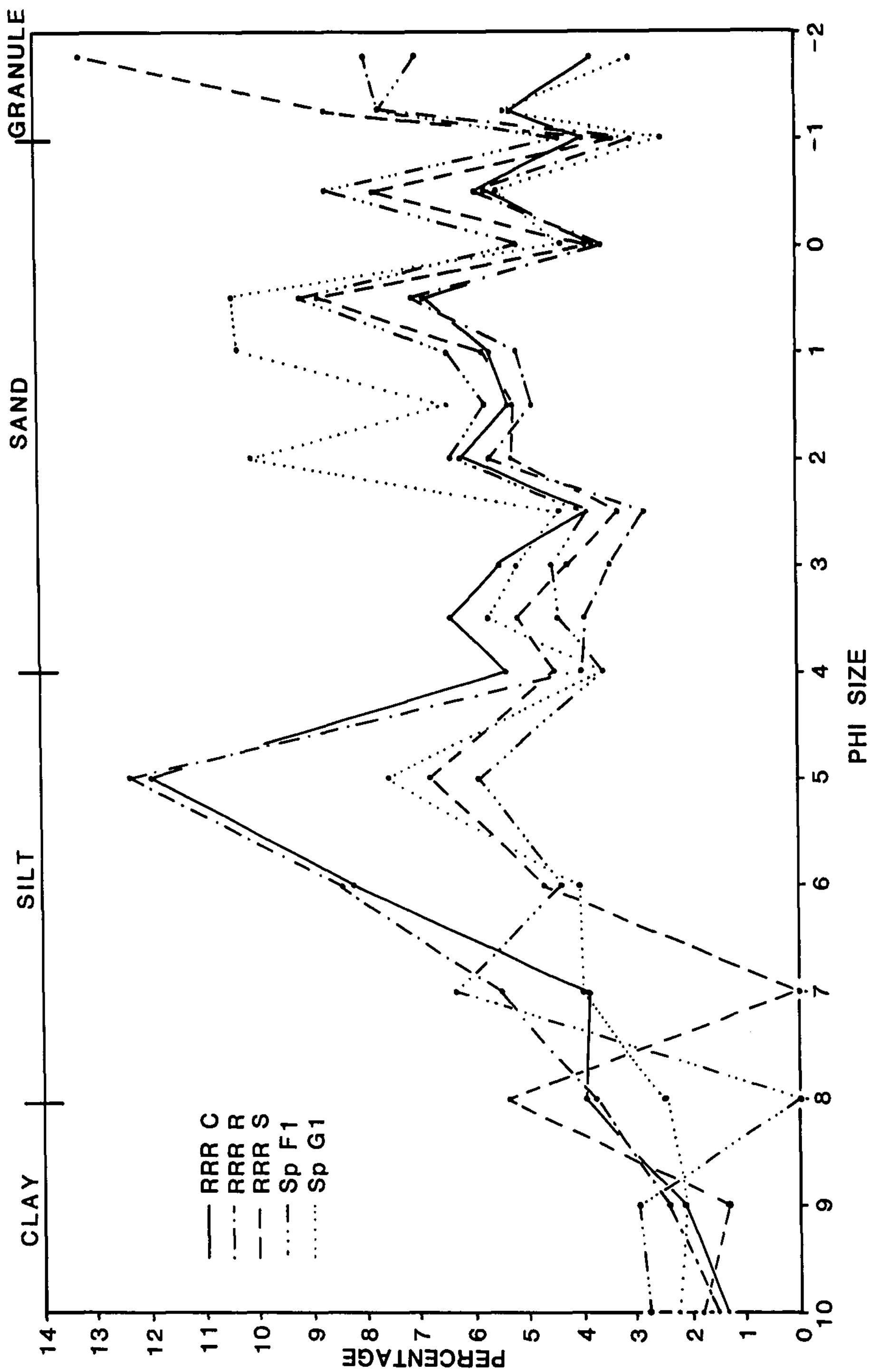

Figure 7: Size distribution of five matrix samples.

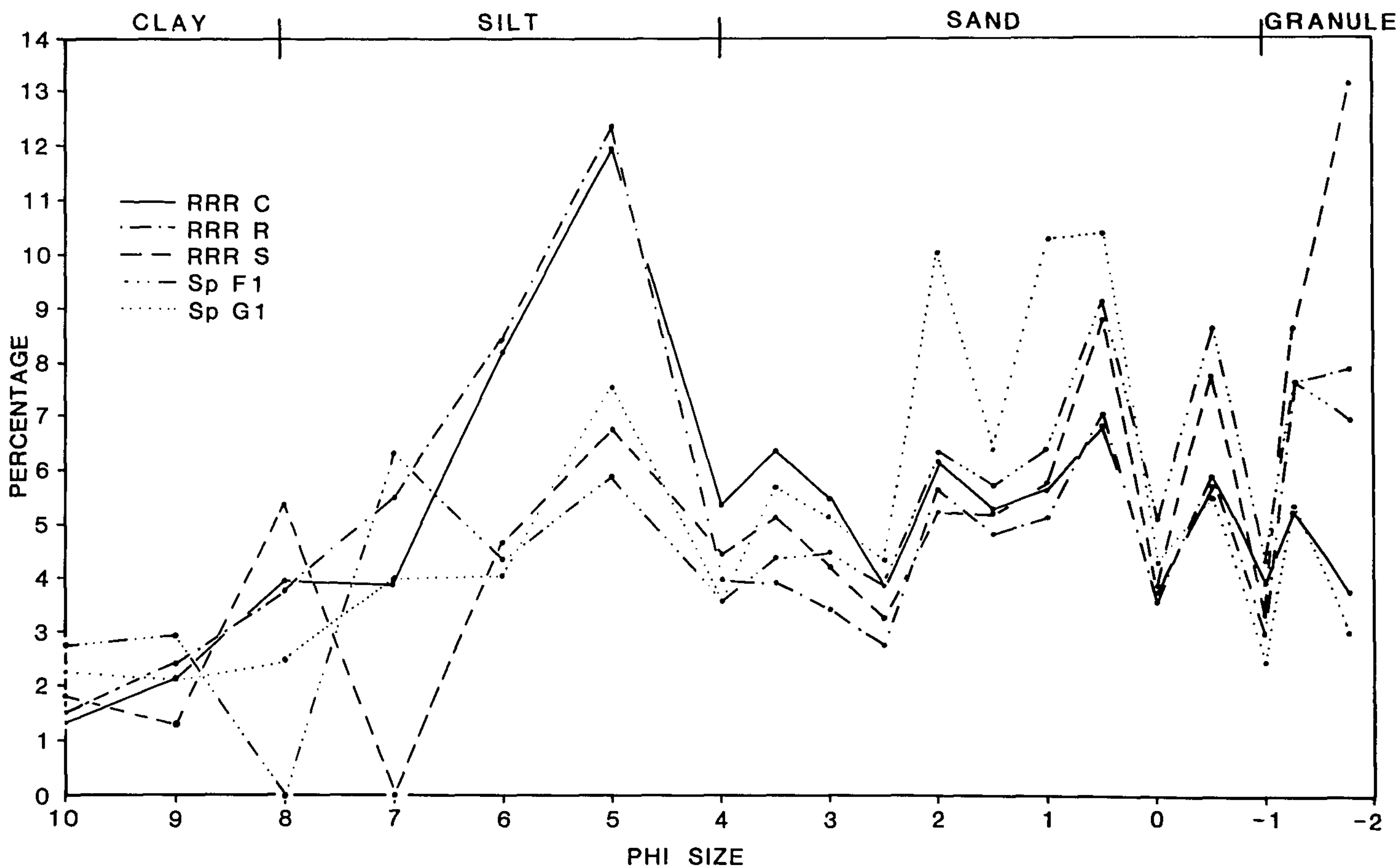

Figure 7: Size distribution of five matrix samples.

6.2 PROVENANCE

Provenance determinations using pebble and boulder lithologies and heavy mineral species were made in an attempt to determine the source of the ridgetop material and to provide an idea of transport path. The results are presented in Plates 2 through 6. Raw data are found in Appendices 2 through 5.

Boulder lithologies (Appendix 2) and pebble lithologies (Appendix 3) were analyzed in two forms, referred to as the "long form" and the "short form." The long form consists of 9 lithology catagories: aplite, quartz monzonite, vein quartz, biotite andesite, gray metasediments, banded metasediments, light and/or calcareous quartzite, Challis Volcanics, and cryptocrystalline quartz (Plate 2, Plate 4). The short form is grouped into three lithology catagories (Plate 3, Plate 5): intrusives (including aplite, quartz monzonite, vein quartz, and biotite andesite), metasediments (including gray metasediments, banded metasediments, and light and/or calcareous quartzite), and extrusives (including Challis Volcanics and cryptocrystalline quartz). All data sets indicate that intrusive lithologies, especially quartz monzonite, are common over the study area. Metasediments are more commonly noted on Railroad Ridge than the southern ridges. Extrusive lithologies are found only at sample sites which are located in the areas underlain by Challis Volcanics bedrock. Several of these sites (RRR L, RRR O, RRR P) may be in deposits not genetically related to the diamicton.

Heavy mineral species data was analyzed in two different ways. The first was by including all highly altered (unidentifiable) grains, termed "alterites," as part of the 300 point heavy mineral species determination (Appendix 4). The second method was a species determination of 300 grains, disregarding all alterites (Appendix 5). The results of the two methods statistically did not yield significantly different results, so only the non-alterite data was used in analyzing the provenance of the samples. The heavy mineral catagories are as follows: biotite, opaques, diopside, tremolite, augite, muscovite, chlorite, hornblende, apatite, sphene, and isotropics. Plate 6 is a plot of simple component percentages. Biotite, an accessory mineral in quartz monzonite, is common over most of the area. High augite and hornblende percentages are noted at sites with extrusive lithologies in the pebbles, boulders, or underlying bedrock. Opaques and also hornblende are associated in a general manner with intrusive lithologies; diopside and tremolite are generally associated with metasediments. Muscovite, chlorite, apatite, sphene, and isotropics occur only in very small percentages in most samples. Each of these may be associated with more than one bedrock lithology.

7 DISCUSSION

7.1 HYPOTHESES

The large boulders contained within the Railroad Ridge diamicton are the major reason why previous workers (Ross, 1929; Ross, 1937; Ross, unpubl.; Tshanz et al., 1974) have favored a glacial origin for the Railroad Ridge diamicton. In general, alternate working hypotheses have been neglected. Scott (1973) describes alluvial gravel-capped Tertiary erosion surfaces in the Southern Rockies, noting that they are often inaccurately attributed to ice cap glaciations. A number of mechanisms other than glacial action are capable of transporting enormous boulders. Landslides and rockfalls commonly carry boulders but generally operate on a smaller scale and leave a deposit of significantly different character than that of the Railroad Ridge diamicton. For the same reason torrential streams are not considered. Debris flows involving saturated and overpressured sediments, such as mudflows and solifluction, are known to transport large boulders. This type of depositional mechanism presents the most likely alternative to glacial action. Solifluction is not considered separately from mudflow as it is merely a specialized case.

Mudflows are competent to transport large boulders. At Wrightwood, California, a mudflow transported boulders 4 to 6 feet (1.2 to 1.8 m) in diameter one mile (1.6 km) and boulders 2 feet (0.6 m) in diameter up to 15 miles (24 km), along a gradient progressively decreasing from 9° to 1° (Sharp and Nobles, 1953). Observations of mudflows in progress verify their competence to transport boulders exceeding 15 feet (4.5 m) in length (Blackwelder, 1928). Sharp and Nobles (1953, p. 554) in describing the texture of mudflow deposits, note that "the material looks exactly like some glacial tills."

Mudflows contributing up to 40% of debris to some alluvial fans have been documented (Blissenbach, 1954); fans can also be built by a combination of talus fall, sheetfloods, streamfloods, and streams. Large boulders carried by mudflows or streamfloods are not uncommon in alluvial fans (Buwalda, 1951; Sharp and Nobles, 1953; Blissenbach, 1954; Bull, 1964; Scott, 1973; Garner, 1974; Howell and Link, 1979). Blackwelder (1928, p. 465) describes semiarid-climate alluvial fans as often being "strewn with large, isolated boulders" and consisting of "a heterogeneous mixture of particles of all sizes, which in that respect resembles glacial till."

Results derived from laboratory analyses and field observation can be combined to yield information on the possible environment of deposition, source, and age of the Railroad Ridge diamicton. Two working hypotheses are considered for the origin of the diamicton. They are:

1. the Railroad Ridge diamicton is a till, and
2. the Railroad Ridge diamicton is a fan-building mudflow deposit.

The results are synthesized and analyzed with respect to these two hypotheses.

7.2 SEDIMENTOLOGICAL PROPERTIES

The size analyses and statistical parameters of the unweathered Railroad Ridge diamicton matrix samples provide a basis for comparison to other types of diamictons. Some of the diamictons of known origin available for comparison include continental glacial tills with high gravel, sand or silt percentages (Deane, 1950), and alluvial fan-building mudflows derived from gneissic terraine (Sharp and Nobles, 1953). The cumulative percentages of the five Railroad Ridge diamicton matrix samples are plotted against those of other diamictons in Figure 8. The plots of the Railroad Ridge diamicton generally parallel those of the other deposits. This analysis alone cannot discriminate in which, if either, category the ridgetop deposit belongs.

Landim and Frakes (1968) discuss methods of distinquishing between various diamictons using Folk and Ward's (1957) statistical parameters. Figure 9a (after Landim and Frakes, 1968) is a graph of mean particle size versus standard deviation for continental tills, alluvial fans, and mudflows. The five unweathered Railroad Ridge diamicton matrix samples analyzed in this study and seventeen samples of debris flow, alluvial, and colluvial matrix sediments derived from gneiss and quartz monzonite bedrock (Madole, 1982) have been added to this graph. The Railroad Ridge diamicton samples fall within the alluvial fan/mudflow grouping, although near the interfingering boundary with the till grouping. Since these tills are continental, relatively higher percentages of silt and clay size particles are

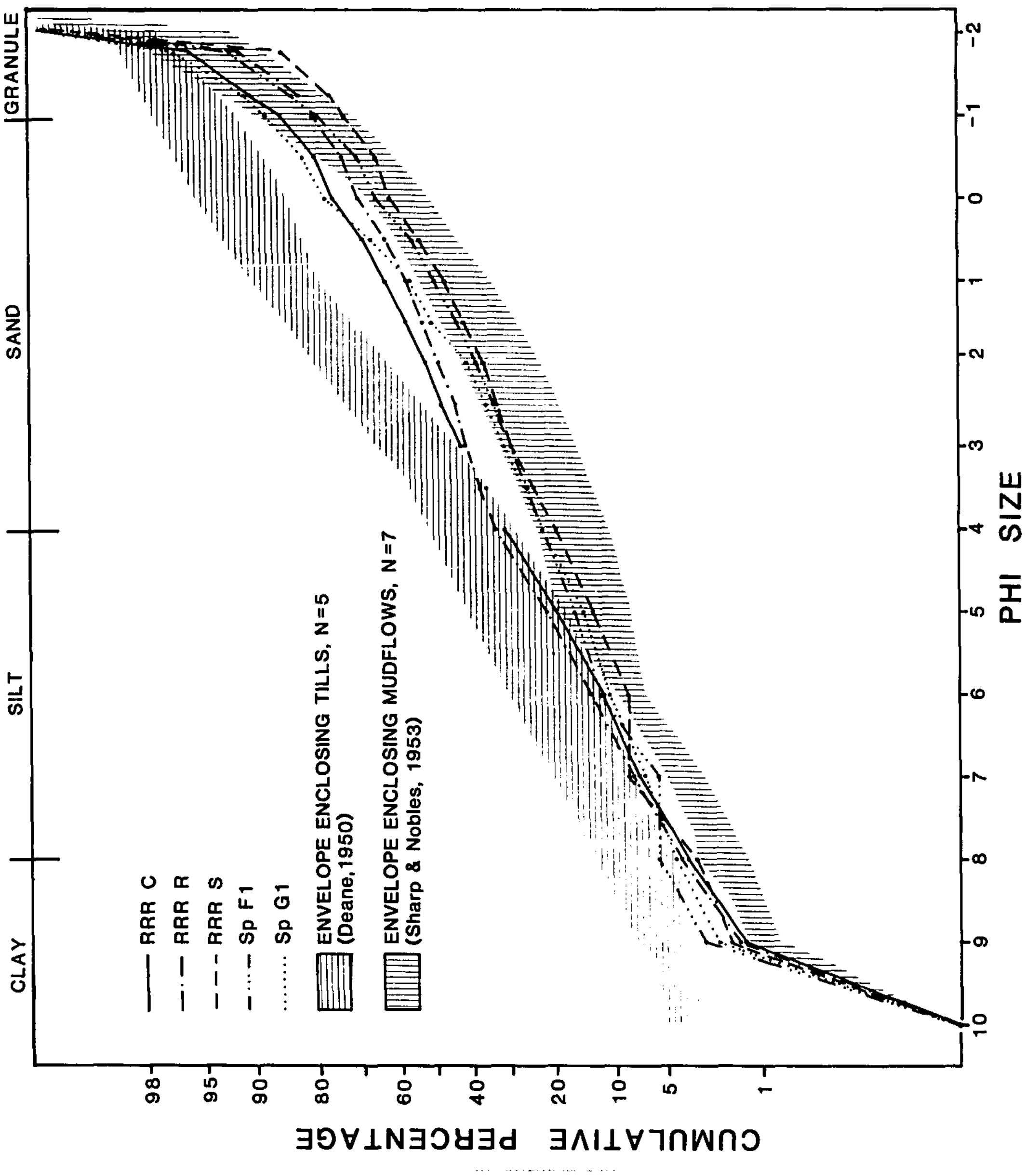

Figure 8: Cumulative size percentage plot of the Railroad Ridge diamicton and other diamictons.

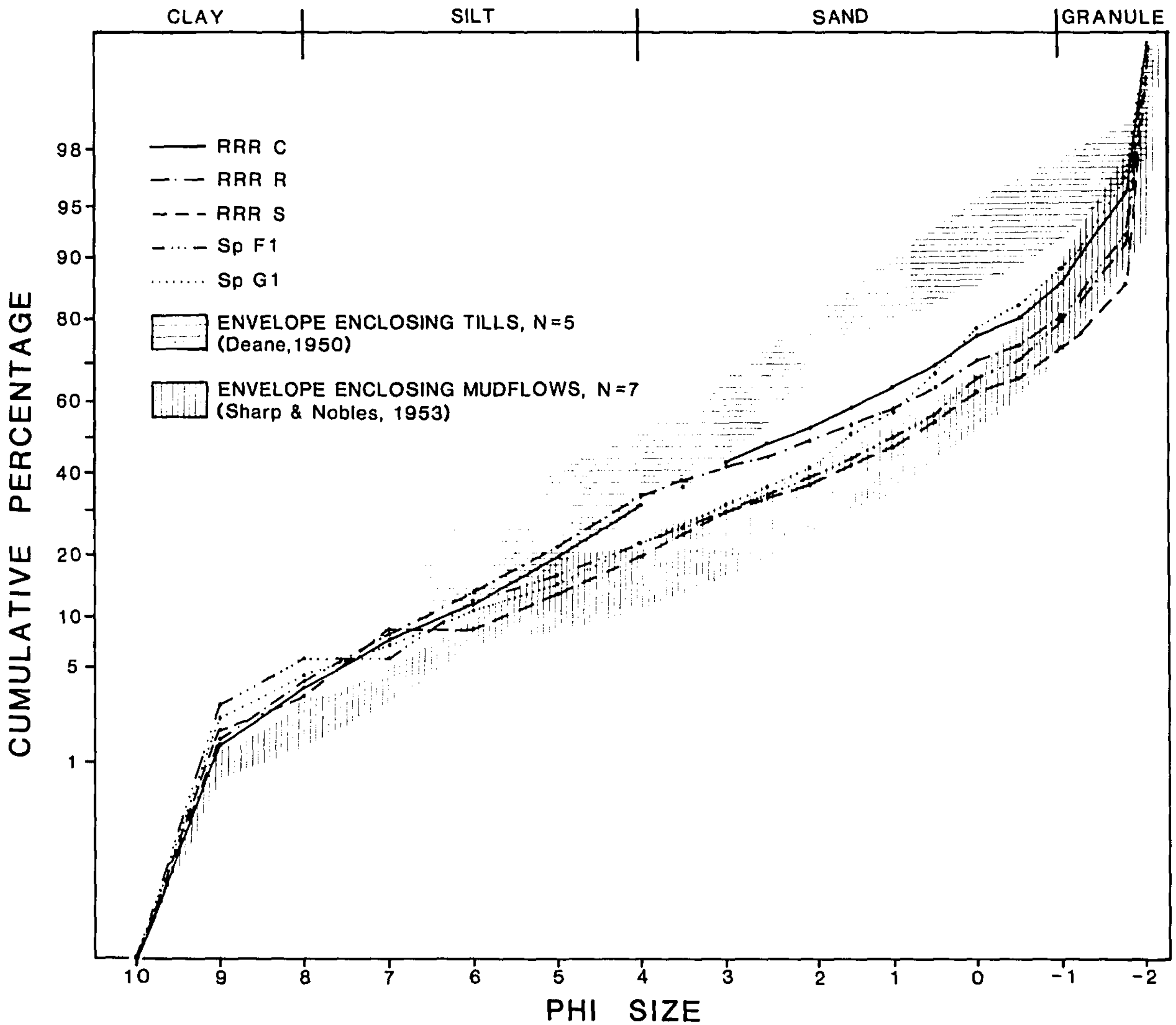

Figure 8: Cumulative size percentage plot of the Railroad Ridge diamicton and other diamictons.

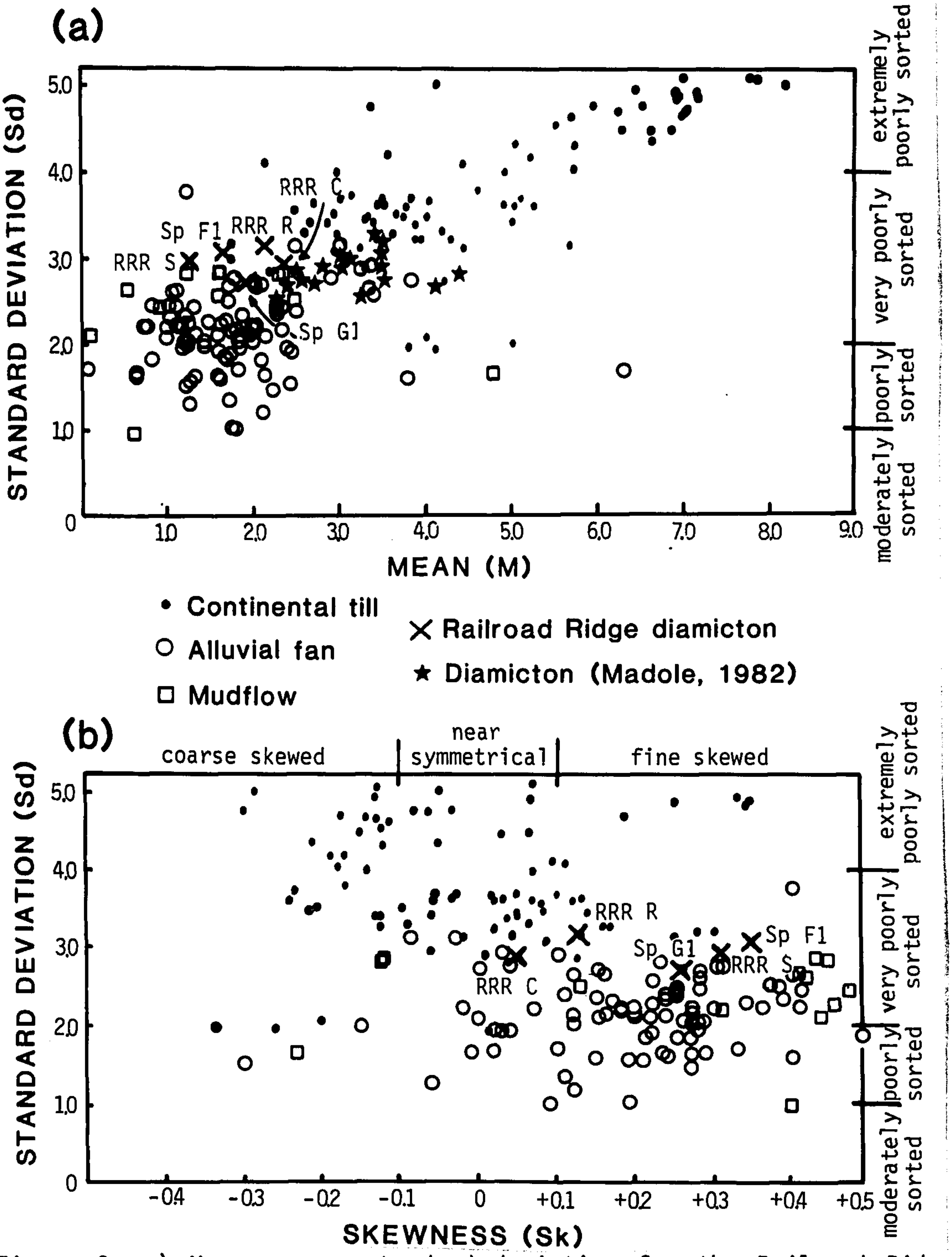

Figure 9: a) Mean versus standard deviation for the Railroad Ridge diamicton and other diamictons (after Landim and Frakes, 1968).
b) Skewness versus standard deviation for the Railroad Ridge diamicton and other diamictons (after Landim and Frakes, 1968).

present than would be expected for alpine tills. No size analyses of the latter were available for comparison. The Railroad Ridge diamicton samples are generally coarser than Madole's (1982) diamicton samples (analyzed on the basis of the smaller than -1.0 phi fraction), but have approximately the same standard deviation range, indicating a very poorly sorted matrix (Figure 9a). In general, tills range from very poorly sorted to extremely poorly sorted while mudflow and alluvial fan deposits range from poorly sorted to very poorly sorted. Blissenbach (1959) notes that a sheetflood (mudflow) deposit in a small alluvial fan in Arizona has a standard deviation of about 3.0, which is also the average for the five Railroad Ridge diamicton matrix samples.

Figure 9b (after Landim and Frakes, 1968) shows skewness versus standard deviation data for the same deposits. Here the Railroad Ridge diamicton shows a similar distribution to that noted in Figure 9a, however there is a wider range of skewness values (Figure 9b) within the samples than of mean values (Figure 9a). In both figures, RRR C and RRR R fall closer to the tills than RRR S, Sp F1, and Sp G1.

Landim and Frakes (1968) derived a discriminant function from their comparisons of tills and alluvial fan deposits (including fan-building mudflows). Based on Folk and Ward's (1957) statistical parameters (as defined in Table 2), it was determined that for the equation:

$$D = 0.00405\ M + 0.02381\ Sd - 0.05616\ Sk + 0.10365\ (K/(1 + K))$$

D = 0.12809 for discrimination between continental till and alluvial fan deposits. Values of D less than this indicate deposition in an alluvial fan environment, and values greater than 0.12809 indicate till. Overlap of Landim and Frakes' (1968) samples is 12 percent; the mean value of D for tills is 0.16121 with a standard deviation of 0.02312, and the mean value for alluvial fan deposits is 0.10225, with a standard deviation of 0.01317. Statistical significance is at the 0.1 percent level. The five fresh Railroad Ridge diamicton samples have the following D values: D(RRR C) = 0.1242, D(RRR R) = 0.1215, D(RRR S) = 0.1067, D(Sp F1) = 0.1109, and D(Sp G1) = 0.1121, with D(average) = 0.1151. As with the statistical plots (Figures 9a and 9b), the samples all fall within the upper part of the alluvial fan deposit range. RRR C and RRR R fall closest to the boundary with till; the remaining three samples fall within one standard deviation of the mean value of alluvial fan deposits. This evidence shows that the Railroad Ridge diamicton has textural parameters more closely resembling those of alluvial fan and mudflow deposits than those of continental tills.

Analysis of sedimentological characteristics noted in the field contributes to the understanding of the diamicton's possible origins. Since mudflows, as well as glaciers, are competent to transport large boulders, the presence of boulders alone does not support either hypothesis preferentially. Seeland (unpubl.), however, noted that on Red Ridge the average clast size tends to decrease to the east. He hypothesized a torrential fluvial transport mechanism despite the lack of rounded cobbles and fluvial bedding characteristics. Mudflows characteristically leave a decreasing clast size distribution away from the source area (Sharp and Nobles, 1953). This is not true of glaciers; they do not selectively deposit the largest boulders nearest to the source area.

Lines of boulders were noted on the surface at the west end of Railroad Ridge. These are probably due to bulldozing along local mining claim boundaries.

In the fresh Silver Rule cirque cut in the Railroad Ridge diamicton two striated cobbles were found. If due to original deposition of the diamicton, these striations would not support either a mudflow or a glacial hypothesis since both mechanisms can striate included clasts (Blackwelder, 1930). A glacial origin for these striations cannot be ruled out, however, since they may have been reworked by the Silver Rule glacier. In other areas of the Railroad Ridge diamicton, lack of striated clasts and "typical" glacially faceted stones, especially in the softer lithologies present, argues against a glacial origin for the diamicton.

Another unusual feature of the Railroad Ridge diamicton is its apparent lack of interstratification with sorted deposits. Excavations in freshly-eroded faces on Railroad Ridge and on "the Spur" did not display any evidence of water-laid material; no rounded clasts or fluviatile interbeds were found. This lack of sorted material could be due to inadequate sampling over the exposures. Both thick glacial and alluvial fan deposits would be expected to have some interstratified water-laid material. Tills are commonly interbedded with or contain pockets of outwash gravels. Alluvial fans may be built by a combination of talus fall, debris flows (including mudflows), streamfloods, and streams. Such fans may show good to poor stratification, parallel to the fan surface, depending on the relative percentages of stream and mudflow deposits. If the latter predominate, individual deposits may be 15 to 20 feet (4.5 to 6 m) thick (Blissenbach, 1954). The lack of sorted deposits within the Railroad Ridge diamicton rules out typical alluvial fans as a modern analog.

The Railroad Ridge diamicton shows some crude stratification in the form of the subhorizontal brown zone and subhorizontal concentrations of large boulders in the scarp on "the Spur." The former may be a paleosol as the color indicates oxidation of the normally gray diamicton, and pebbles collected from it were highly weathered. Within the brown zone are apparent layers, differing in color (see Figure 5). These may represent soil horizons, groundwater effects, or creep effects. Although there are no boulders within this brown zone, the size analysis does not indicate any significant difference between its matrix (sample Sp F1) and that in other areas of the deposit (Figures 7 and 8). A paleosol could be consistent with either an alluvial fan or glacial deposit; however the subhorizontal form is less consistent with till deposits, which typically have hummocky upper surfaces. Melton (1965) describes a buried mature red soil on a relict alluvial fan, Frye Mesa, in southern Arizona. This subhorizontal paleosol separates an older, poorly stratified, stream-deposited, cobble-and-boulder gravel from a younger deposit of very large boulders in an unsorted matrix, and represents a hiatus in deposition. If the brown zone is a paleosol, this would indicate at least two major depositional episodes for the Railroad Ridge diamicton.

Concentrations of boulders in crude layers approximately parallel to the original surface of the deposit were observed. It is unknown whether they are a primary depositional feature or a secondary feature due to downslope creep on the escarpments. Boulder pavements have been found between tills. Layering of boulders within alluvial fan deposits has not been described, but Blackwelder (1931b) notes that individual detrital layers are parallel to a fan's surface. Such a layering of boulders may represent different depositional episodes, which would be consistent with either multiple glacial advances or intermittent mudflow activity.

7.3 PROVENANCE

Analysis of the boulder lithology data, both the long form (Plate 2) and short form (Plate 3), yields the following provenance relations. Quartz monzonite, which in all areas comprises the majority of intrusive boulders (Plate 2), predominates on "Trimline Ridge," Red Ridge (except at Red A2 and Red C2), and "the Spur" (except Sp B1). On Railroad Ridge, the intrusive percentages tend to decrease to the northwest, with metasedimentary lithologies increasing concomitantly (Plates 2 and 3). This distribution is probably due to increasing distance of transport over metasedimentary bedrock on the west end of Railroad Ridge (see Figure 2), especially where the diamicton is thin. Quartz monzonite boulders were not found at RRR N where there is a scattering of stream cobbles on bedrock, nor on "Agate Ridge" where an associated deposit of black basalt boulders on basalt bedrock occurs.

Metasediments dominate over intrusives at six of the Railroad Ridge sample sites (RRR A, RRR D, RRR H, RRR K, RRR L, RRR Q). Metasediments are found close to the high peaks on the southern ridges (Tr C4, Red C2, Red A2, Sp B1, Sp C1, Sp D1) but dominate over intrusives only in samples Sp B1 and Red A2 (Plate 3). A general trend of higher percentages of light-colored and/or calcareous quartzite than grey metasediments is noted in the long form boulder data (Plate 2). Banded metasediments are confined to a relatively small group of sites (Sp B1, Sp C1, RRR A, RRR B, RRR C, RRR D, RRR E). Since these are interbedded light and grey metasediments, further transport may break them up into color components along bedding planes or cleavages. A bedrock outcrop of this lithology is located on "the Spur" above Sp B1. Transport northward prior to development of the Jim Creek drainage is indicated by the distribution of banded metasediments (Plate 2).

Extrusive boulders (Challis Volcanics) are found only at four sample localities (Plate 3): at RRR O and RRR P, two postulated early valley glacial deposits; and at RRR L and RRR M on the north edge of the deposit, where boulders rest on or near Challis Volcanics bedrock. This very small to nonexistant extrusive boulder component may indicate a lack of effective erosion of the planated post-Challis surface. Since boulder counts were made on the deposit's surface it is possible that lower layers may contain higher extrusive clast concentrations. That the Challis can be transported and survive as boulders is demonstrated by the presence of extrusive boulders in valley tills (Zigmont, 1982).

The pebble lithologies (Plates 4 and 5) have the same general distributions as the boulder lithologies (Plates 2 and 3), but the percentages of quartz monzonite pebbles are overall lower than quartz monzonite boulders. This may be due to the relative ease of disintigration of quartz monzonite pebbles into their component crystals. As in the boulder count data, RRR E is locally high in intrusives in an area dominated by metasediments, and Sp B1, Red A2, and Red C2 have locally high metasediment concentrations on ridges dominated by intrusive lithologies.

Distribution of metasedimentary pebbles (Plate 5) is much wider than that of metasedimentary boulders (Plate 3). Gray metasediment pebbles are approximately as common over the area as the light and/or calcareous quartzite pebbles (Plate 4). This is due in part to better preservation of gray silicic argillite clasts than easily leached calcareous pebbles. The relative scarcity of the gray metasediments in the boulder counts (Plate 2), may be due to disintegration of argillite boulders along bedding or cleavage planes, which would also add material to the pebble fraction.

Extrusive pebble lithologies (Plate 5), like extrusive boulders (Plate 3), are generally confined to the far edges of the deposit and to the high lateral moraines samples (RRR P, RRR O).

The heavy mineral data indicate some general relationships (Plate 6). Biotite and opaques are primary accessory minerals of quartz monzonite. Where biotite or opaques occur in high percentages (Plate 6) a general correlation can be seen when compared to the distribution of quartz monzonite clasts (Plates 2 and 4), although individual samples do not always show a one to one correspondence. This may indicate that the matrix was sourced from the same general area as the clasts or, to a large extent, derived *in situ* from the breakdown of quartz monzonite clasts. Locally, opaques may predominate (RRR P, Sp E1, Sp G1), but no pattern of relative distribution is indicated aside from slightly higher opaque percentages in the southeastern part of the study area.

Diopside and tremolite are common accessory minerals to the metasedimentary lithologies. These minerals are more abundant on the northwest side of Railroad Ridge (Plate 6) where metasedimentary clasts also predominate (Plates 3 and 5). Moderate concentrations of diopside and tremolite are found on Red Ridge (except at Red E2, Red F2, and Red H2) and low concentrations or none are found on "Trimline Ridge" or "the Spur" (except at Sp B1).

Augite, an accessory mineral of the Challis Volcanics, is rare over most of the deposit (Plate 6). Concentrations of this mineral are high at RRR L, RRR M, and RRR O, correlating with distribution of extrusive boulders (Plate 3). High concentrations elsewhere are explained by proximity to volcanic bedrock: Red B2L is in Challis Volcanics regolith, Red B2U immediately overlies Red B2L, and Red A2 is on landslide-transported diamicton (Plate 1) underlain by Challis Volcanics. Small percentages of augite noted in locations not associated with extrusive bedrock can be attributed to mis-identification of green-tinted diopside, wind-transported sediments, or the presence of minor augite in other lithologies.

Hornblende, muscovite, apatite, chlorite, sphene, and isotropics are minor accessory minerals which generally occur only in small percentages. Hornblende, an accessory mineral of both quartz monzonite and Challis Volcanics is locally abundant at RRR L, Red D2, Red H2, and Tr B4 and is more common on the two southern ridges than in the north. Muscovite, an intrusive accessory, is present where intrusive clasts predominate but is especially common at Sp E1. A relatively high percentage of apatite is found at Red C2, otherwise percentages are low. Chlorite, sphene, and isotropics occur sporadically across the diamicton in only very small percentages.

The conclusion that can be drawn from this body of data is that without distinctive lithologic provinces in the highlands (see Figure 2), the results of the provenance analyses can only delineate gross variations. In an attempt to derive more meaning from this data, statistical analyses of the R-mode and Q-mode types were applied. The groupings of data thus achieved did not exhibit any meaningful pattern relative to the sample site positions; thus they are not discussed.

A second objective of the provenance study was to determine whether the Railroad Ridge diamicton can be easily separated from deposits of the yougest major valley glaciation on the basis of lithology. Zigmont (1982) has investigated this possibility in depth; his results are summarized below.

Metasedimentary to intrusive ratios for boulders and pebbles in the valley till of lower Big Boulder Creek are consistantly higher than in the diamicton on Red Ridge (with the exception of boulder counts at Red A2 and Red C2). Valley tills of Jim and Silver Rule Creeks cannot be differentiated from the diamicton on Railroad Ridge on this basis, however. Metasedimentary to intrusive ratios for the diamicton on "Trimline Ridge" are all extremely low for both boulders and pebbles. These ratios are variable on "the Spur" and cannot be used to distinguish diamicton there from tills in Jim Creek and upper Big Boulder Creek (Zigmont, 1982).

Tills in the lower reaches of Big Boulder Creek contain significant percentages of extrusive boulders and pebbles, compared to the only sample on Red Ridge, Red G2, which has any extrusive component at all (2% extrusive pebbles). Significant concentrations of extrusive boulders in till also occur along the east side of Silver Rule cirque and downstream. This is attributable to the outcrop pattern of the Challis Volcanics (Zigmont, 1982). The diamicton on adjacent areas of Railroad Ridge does not contain extrusive boulders (except RRR L and RRR P), thus this component of the till must have been eroded from the cirque wall bedrock, compared to the quartz monzonite which can only be attributed to reworked Railroad Ridge diamicton.

Heavy mineral concentrations differ between the Railroad Ridge diamicton on Railroad and Red Ridges and the valley tills in Big Boulder, Jim, and Silver Rule Creeks in that the diamicton contains a higher percentage of biotite than the tills (Zigmont, 1982) with few exceptions (11% of samples on Railroad and Red Ridges have biotite concentrations below 5%; 12.5% of samples from late valley tills have biotite concentrations above 5%). Biotite concentrations in diamicton on "the Spur" and "Trimline Ridge" are also high, in all cases exceeding 15%. The reason for variability of biotite percentages between the Railroad Ridge diamicton and the valley tills is suggested to be the weathering of altered unstable minerals (i.e. tremolite, diopside) increasing the relative concentrations of biotite in the older deposit (Zigmont, 1982). An alternate explanation for this phenomenon is that the predominantly quartz monzonite boulder character of the Railroad Ridge diamicton implies a source area rich in associated minerals, especially biotite. Fresh biotite crystals would also be released during *in situ* weathering of the quartz monzonite boulders, which have produced large amounts of grus.

Zigmont (1982) suggests that provenance may be able to resolve the problem of association of the high gravel deposits along the valley walls of lower Big Boulder Creek (see Figure 3: G, H, M, N). Deposit G (Figure 3) has high percentages of metasedimentary clasts which distinguishes it from the diamicton on Red Ridge but not that on Railroad Ridge. One of the samples from G, RRR 0, also has significant percentages of extrusive clasts; the other lacks extrusives entirely. Significant percentages of biotite (12%, 20%) are also present in this deposit, differentiating it from the younger valley tills. Deposit H (Figure 3) has a pebble provenance similar to the diamicton on Red Ridge, but the presence of metasedimentary boulders associates it with the valley tills, rather than the eastern portion of the diamicton on Red Ridge. A low concentration of biotite (2%) also differentiates H from the ridgetop diamicton. Three other samples from high gravel deposits are as follows: one from the ridges at M and N (Figure 3), one from below these ridges, and one at an identified high deposit (but unmapped by Zigmont) on the north wall at the mouth of Big Boulder Creek. These can be differentiated from the diamicton on Red Ridge by the presence of metasedimentary and extrusive boulders at and below M and N, high percentages of volcanic pebbles at all three, and the absence of biotite (Zigmont, 1982).

Zigmont (1982) concludes that the origin of the deposits G and H cannot be verified by provenance data. Since previous ice flow reconstructions indicated to him that these deposits could not be deposited by a glacier in Big Boulder Creek (see subsection 2.3 Quaternary Geology) he feels that the question of origin for these deposits is unresolved. Regarding the remaining three samples, Zigmont (1982) suggests that they were derived from one or more "pre-canyon" glaciers that flowed down Little Boulder Creek, Big Boulder Creek, or the East Fork of the Salmon River. In looking for a reasonable and common origin for all of these elevated valley gravel deposits, it is noted that they occur at an elevation of 1000 feet (305 m) above the current stream in Big Boulder Creek, 500 feet (152 m) at the mouth of Big Boulder Creek, and from 800 to 1800 feet (244 to 549 m) above the East Fork at the east end of Red Ridge. A possible explanation is that all of these deposits can be attributed to an extensive early glaciation confined to the existing drainages of the region which since that time have been reglaciated and extensively downcut. Provenance differences between the high and low valley deposits could possibly be attributed to a changing distribution of bedrock outcrop over the course of at least two major valley glaciations.

If such early valley glaciation did take place, the position of diamicton patches in Silver Rule cirque at altitudes of 9400 feet

(2865 m) (Plate 1: (5)) can be more easily explained. These do not hold a ridgetop position like the "typical" diamicton, rather they lie high on the valley wall and in a col, indicating deposition after valley incision. An early extensive glaciation could easily deposit material in this position, especially with large amounts of unconsolidated debris available from Railroad Ridge. Provenance suggests that RRR P (Plate 1: (5)) should be attributed to reworking of the Railroad Ridge diamicton in an early glacial episode, as this site has high extrusive clast concentrations like the tills of Silver Rule Creek. A low divide separates the Silver Rule drainage from Big Lake Creek (Plate 1: (1)). It is further suggested that much of the anomalously located (valley-bottom) diamicton in this latter drainage may have been emplaced by debris-laden ice of the postulated early glaciation overtopping the divide at 9080 feet (2768 m) and depositing reworked Railroad Ridge diamicton in the head of Big Lake Creek. Zigmont (1982) has suggested that the diamicton here was deposited by mass-wasting of the adjacent diamicton since there is no sign of a late valley glaciation, however this does not adequately explain the deposition of boulders up to 400 feet (122 m) above current stream level along the northern valley wall (Plate 1: (19)). Downcutting since this early glacial episode would have destroyed any remnants of a glacial valley profile, if indeed enough ice was present for significant erosion to occur. A sample in the low divide, RRR L also has high concentrations of extrusive clasts; this may be attributed either to the local bedrock or to divide overtopping.

Despite the lack of detailed provenance results, there is no doubt that the source area for the Railroad Ridge diamicton is the White Cloud stock. This is evident by the nearly ubiquitous quartz monzonite boulders, which characterize the diamicton. There are no quartz monzonite outcrops on Railroad Ridge; it is separated from the stock by "the Spur" and the headwaters of Jim Creek. On "the Spur" only very small quartz monzonite outcrops are found. Thus, the presence of quartz monzonite boulders on Railroad Ridge indicates that prior to valley cutting, the source area must have had a different system of divides. The probable generalized orientation of the high areas at the time of deposition of the Railroad Ridge diamicton is shown in Figure 10 (after Ross, 1937) which is contoured from the location of the present high peaks and ridgelines. In this reconstruction the drainage divides lie further east than their current position. Since valley glaciation on the east side of the peaks has been more intensive than that on the west, headward erosion would tend to move the divides westward.

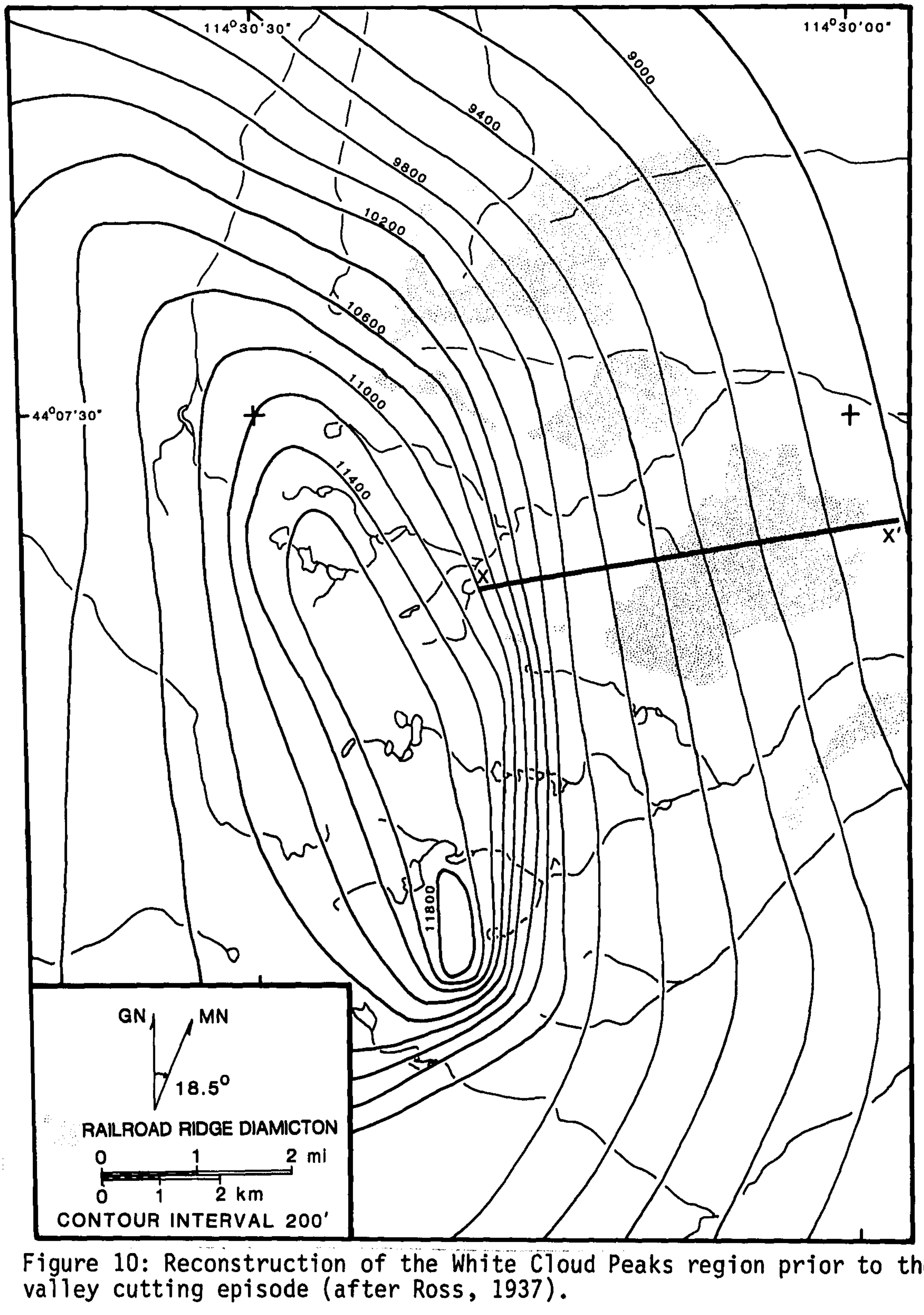

Figure 10: Reconstruction of the White Cloud Peaks region prior to the valley cutting episode (after Ross, 1937).

7.4 GEOMORPHOLOGY

The assumed thickness, present surface morphology, and current geographic position of the Railroad Ridge diamicton are compatible with the fan-building mudflow hypothesis. Valley glacial deposits rarely attain the observed thickness of over 500 feet (152 m) except in instances where large moraines of coalescing valley glaciers are constructed, as in the Copper Basin, Custer County, Idaho (Evenson, 1979, oral commun.). Such moraines, however, are characteristically thicker than they are broad, and typically have narrow ridgelines, neither of which are demonstrated by the geometry of the Railroad Ridge diamicton. Basal till, even in continental deposits, is commonly only 20 to 100 feet (6 to 30 m) deep, with rapid thickening occurring in downfaulted areas and where till fills buried valleys (Christiansen, 1971). As no evidence has been found for extensive downfaulting in the White Cloud Peaks region, the only alternatives, should the deposit be till, is that it is unusually thick or that it lies in a buried valley. The buried valley hypothesis is inconsistent with the location of the source area since the axis of the thickest part of the deposit lies parallel to the axis of the the White Cloud Peaks and is cut perpendicularly by modern drainage. This geometry, however, is typical of alluvial fan deposits, which may attain thicknesses of up to 1000 feet (305 m) (Eckis, 1928). An isopach map of probable original diamicton thickness is shown in Figure 11. This was constructed using the highest remaining exposures of the diamicton on each ridge and assuming a flat, sloping surface projected over the

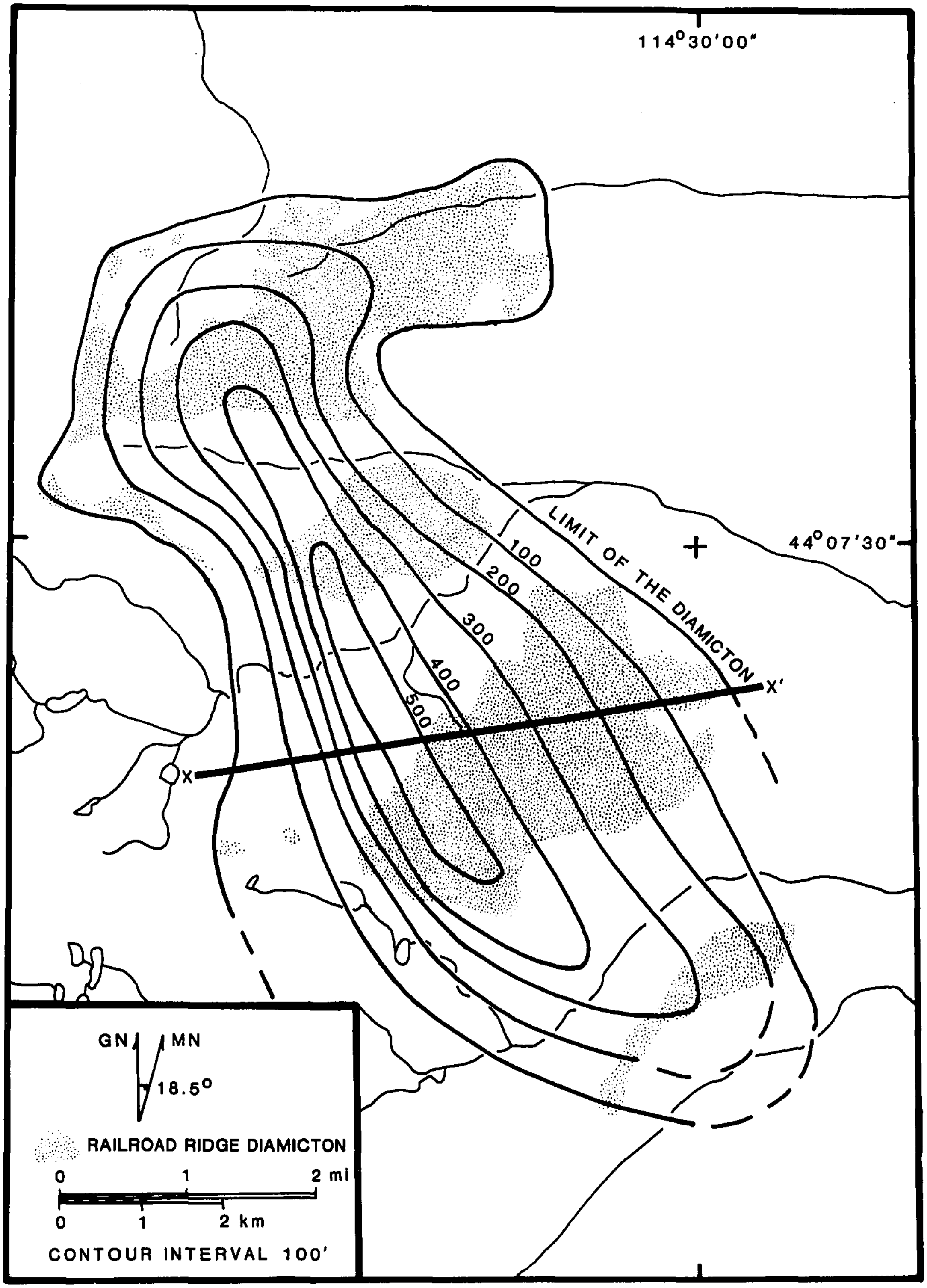

Figure 11: Isopach map of reconstructed Railroad Ridge diamicton thickness.

eroded areas (in essence, the pre-valley cutting surface of the Railroad Ridge diamicton, see Figure 10), then comparing the resulting elevations to the elevations of known and projected diamicton-bedrock contacts. Note that the thickest part of the diamicton trends NNW-SSE (Figure 11), approximately parallel to the axis of the White Cloud Peaks (see Figure 1). On Railroad Ridge (Figure 11) the diamicton extent expands to the northeast in a large lobe along Big Lake Creek. This unusual configuration may be due to post-depositional transport of the diamicton.

Comparison of the reconstructed regional surface prior to valley erosion, as contoured in Figure 10, with measured surface slopes (Figure 6) may indicate where the diamicton's surface has been eroded since deposition. Transects A, B, D, F, and I (Figure 6) have measured slopes (5.7°, 3.0°, 4.1°, 2.2°, and 1.7° respectively) which correspond closely to those calculated from Figure 10 (5.1°, 3.3°, 5.5°, 3.5°, and 2.5° respectively). Transects C and H have calculated slopes (3.3° and 2.7° respectively, from Figure 10) which are significantly lower than their measured slopes (7.4° and 7.9° respectively, from Figure 6). Both of these areas have been mapped as "dissected diamicton" (Plate 1) and it is probable that headward erosion by consequent drainage has increased the overall gradient in these two areas. The measured slope at Transect E (11.3°, from Figure 6) is lower than the calculated slope (16.0°, from Figure 10). This may be an artifact of the difficulty of determining the slope over such a short transect. Erosional lowering of areas on the narrow crest of Red Ridge may account for the relatively high measured slope at transect G (3.0°, from Figure 6) versus a calculated slope of 0.9° (Figure 10).

An idealized cross-section based on projected diamicton thicknesses (Figure 11: X to X') and the reconstructed pre-valley surface (Figure 10: X to X') is compared to alluvial fan profiles in Figure 12. The Railroad Ridge diamicton cross section shows a morphology typical of alluvial fans which form at the intersection of a steep mountain front and a relatively flat plain. The concave upper surface slopes away from the mountains at an angle of 2° to 8°, well within the typical range of 1° to 10°, on alluvial fans (Anstey, 1965) (Figure 12). The deepest part of the deposit, 520 feet (158 m) thick on "the Spur," is at the former piedmont angle, the intersection of the steep mountain front and the shallowly sloping post-Challis piedmont surface on Railroad Ridge. While the Railroad Ridge diamicton is probably not a typical alluvial fan, as demonstrated by the lack of interbedded sorted deposits, geomorphic evidence suggests that, whatever the transport mechanism, the deposit originally had a fan-like geometry.

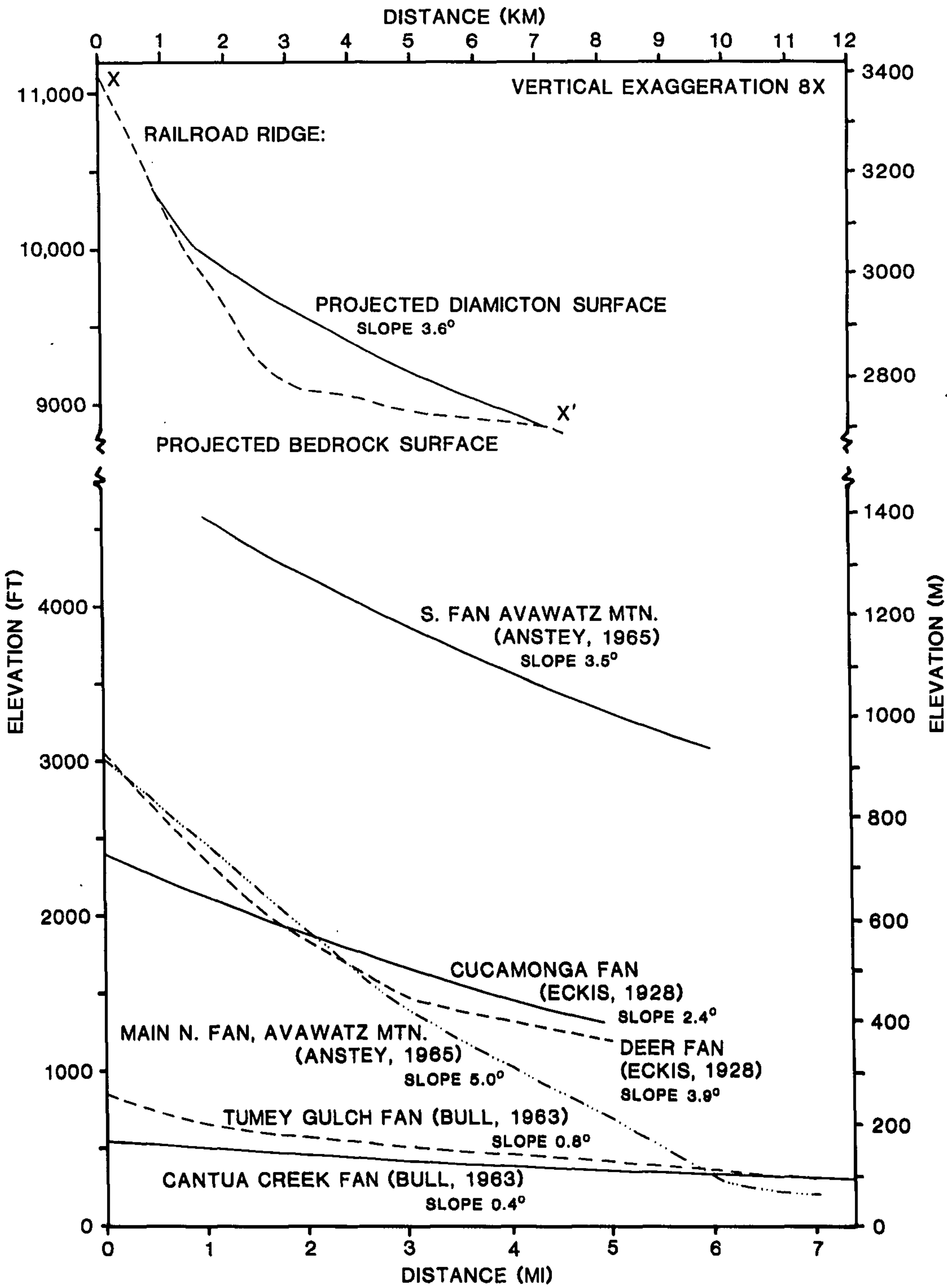

Figure 12: Cross section of the reconstructed Railroad Ridge diamicton and profiles of alluvial fans. Average slopes in degrees are given.

7.5 CHRONOLOGY OF GEOMORPHIC EVENTS

The Railroad Ridge diamicton is bounded in time by two major erosional events. The first is the creation of the post-Challis surface on which it rests; the second is the initiation of major valley cutting. An idealized sequence of events is shown in Figure 13. These events do not have absolute ages assigned to them and have proved a subject of controversy since the early 1900's.

According to Ross (1937), extensive volcanism and associated deformation which ended in early Oligocene was followed by erosion of an assemblege of interrelated pediment-like surfaces, leaving a rolling topography with hills and mountains rising above it (Figure 13a). Thought to be under the influence of local base levels, this surface was widespread throughout Idaho (Ross, 1937), and records a prolonged period of structural stability (Melton, 1965). Such geomorphic development is typical of denudation in an arid to semiarid climate (Garner, 1974), although Ross (unpubl.) denies that conditions at that time were "arid." In the vicinity of the White Cloud Peaks, the post-Challis surface is best expressed on Railroad Ridge, with portions left on the ridgetops to the south, and highly dissected topography to the north maintaining similar ridgetop altitudes (Ross, unpubl.). In this area, the surface dips away from the stock, steeply at first (9°) (Figure 6: D to D') and more gently (3°) (Figure 6: B to B') towards the East Fork of the Salmon River, a typical concave pediment profile (Mabbutt, 1977). The post-Challis erosion surface was first described by Umpleby (1911; 1912) as the "summit peneplain"

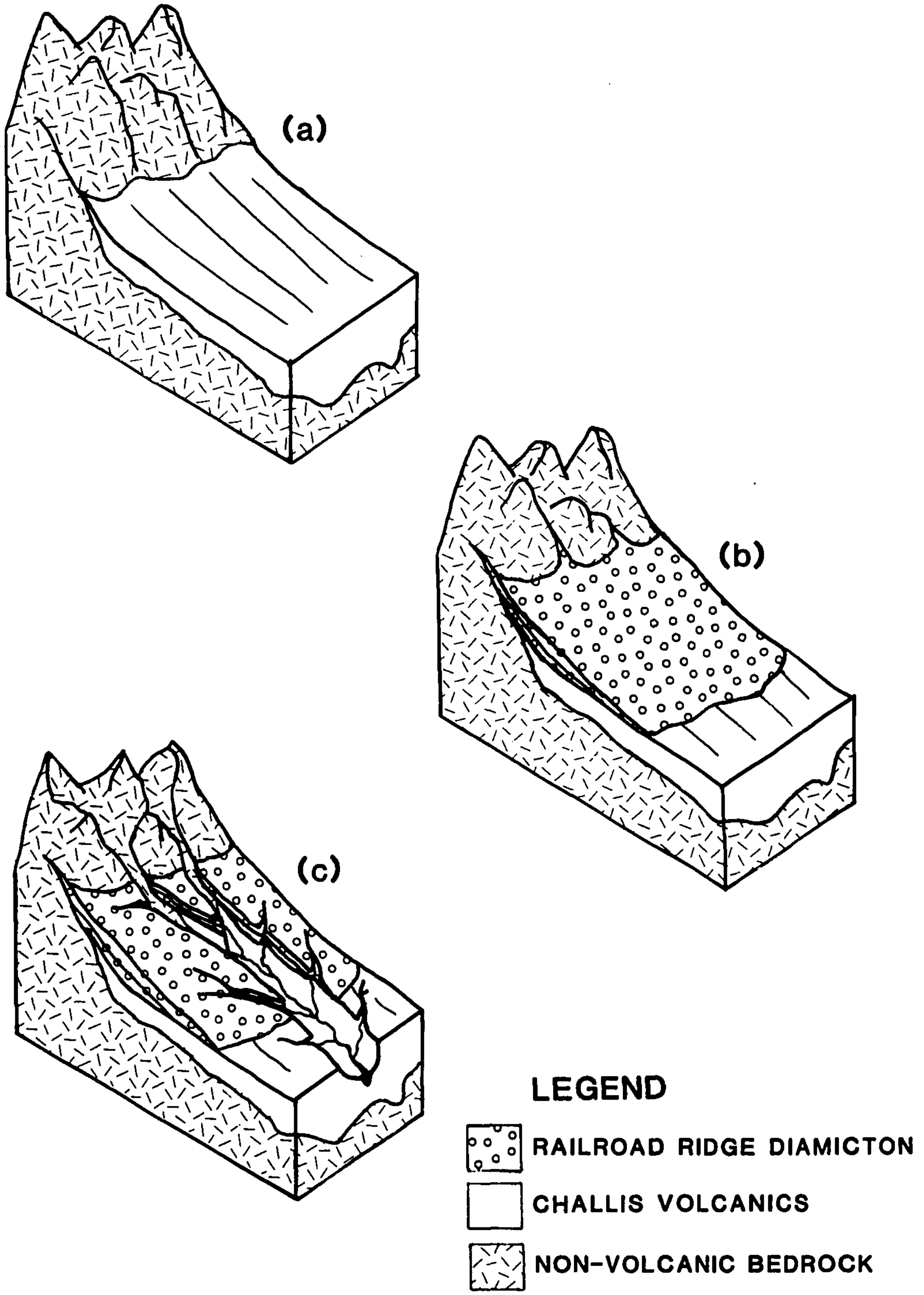

Figure 13: Idealized sequence of geomorphologic events. (a) Development of the post-Challis erosion surface. (b) Deposition of the Railroad Ridge diamicton. (c) Erosion of the modern valleys.

and was assigned an Eocene age because the Challis units were confined to the valleys of the area investigated. Later researchers (Blackwelder, 1912; Rich, 1918), refuted Umpleby's age determination by presenting evidence of the surface's development on Challis Volcanics bedrock and noting lack of deformational features associated with mid-Miocene orogenic activity. This would indicate an age of late Miocene or Pliocene for the post-Challis surface. Ross (unpubl.) states that the diastrophism which deformed the Challis Volcanics occurred earlier than the mid-Miocene, and places the development of the post-Challis surface between the close of the Oligocene and middle or late Miocene.

Following the erosion of the post-Challis surface, the Railroad Ridge diamicton was deposited (Figure 13b). This change from an erosional environment to a depositional environment is probably not the result of normal faulting like that which characterizes alluvial fan depositional environments in the Basin and Range Province. Although Tschanz et al. (1974) and Seeland (unpubl.) have mapped some normal faults of unknown displacement, there is no evidence for any major deformation following development of the post-Challis surface (Ross, 1937). Rather, general uplift of the region is thought to have begun in early or mid-Pliocene (Ross, unpubl.).

The change from a relatively planated bedrock environment, the post-Challis surface, to a depositional environment may be the result of climatic change. It is apparent that the baselevel was not lowered from local to regional, otherwise downcutting would have ensued.

Thus, if humidity increased, it was not enough to cause stream rejuvenation or to transport much debris beyond the present diamicton limits. Instead, there is more evidence for a relative raising of the baselevel since the piedmont angle, where streams normally leave the mountains, has been buried by debris. The simplest manner in which this could have been accomplished is by an increase in debris available for transport to the point where stream courses became choked. This scenario is considered ideal for mudflow formation when combined with intermittent heavy runoff from thunderstorms or snow melt (Bull, 1963). Since no typical alluvial fan facies are present in the exposed faces of the Railroad Ridge diamicton, a mudflow or solifulction deposit or series of deposits with a fan morphology is the hypothesized depositional regime. There are no modern analogs known to the author for this hypothesis.

In general, boulder production in arid areas by weathering along joints is inadequate for production of a large volume of bouldery debris. This is illustrated by the correlation of bouldery alluvial fan formation in the Northern Hemisphere with cold-climate frost-shattering processes in the source areas, for example high altitude, north- or northeast-facing basins (Melton, 1965). The White Cloud Peaks fulfill these geographic criteria. This may indicate that the climate was cold and moist enough for substantial freeze-thaw activity to produce the large quantity of boulders observed in the Railroad Ridge diamicton. The regional uplift described by Ross (1937; unpubl.) may have resulted in significant local climatic cooling. If the climate was relatively cold, solifluction (slow transport over a frozen substrate) may have been the predominant transport mechanism, with associated cryoturbation erasing any evidence of bedding. Whether diamicton deposition may have been associated with the onset of local glaciation is unknown, however the textural similarity of the diamicton to granitic till is intriguing.

Following the deposition of the diamicton, rejuvenation of the local drainage occurred (Figure 13c). This resulted in deep incision of up to 2000 feet (610 m) into the post-Challis surface, aided by extensive Pleistocene glaciations. There are two possible causes of the rejuvenation, which are non-exclusive. The first is climatic change from arid (or semiarid) to humid. This would have the effect of incising an extensively alluviated, planated landscape by redefining the baselevel from local to regional. The result would be the creation of an integrated drainage network where none had existed previously (Garner, 1974). Second is the uplift and deformation which caused abnormal drainage patterns to develop throughout much of the state and rejuvenated the Salmon River (Ruppel, 1967). This rejuvenation was due to the northward tilting of the area as a whole, concomitant with subsidence in the Snake River Plain.

Although no attempt to date the onset of major valley cutting has been made, a comparison of the occurrences of tectonic and geomorphic events does suggest some possible age limits. During the mid-Miocene, volcanic activity began in the western Snake River Plain and spread eastward over time to Yellowstone. The Snake River volcanism was concentrated in three major episodes at 10, 6, and 2 m.y. ago. It produced fault-bounded basins in eastern Idaho (Armstrong, 1978), which in places are filled to a depth of 9000 feet (2743 m) with Miocene and Pliocene tuffs and lake deposits (Ruppel, 1967). Regional uplift, associated with the Yellowstone hot spot, developed during the last volcanic episode 2 m.y. ago (Christianson and Blank, 1972) and is thought by Armstrong (1978) to have resulted in the rejuvation of mountainous topography in the Northern Rocky Mountains, however the extent of this uplift is not elucidated. Concurrent with this rejuvenation, complex drainage changes took place. In eastern Idaho, this is displayed as major drainage reversals in the northwest-trending valleys of the Lemhi River and Birch Creek, Pahsimeroi and Little Lost Rivers, Warm Spring Creek and Big Lost Rivers, with possible influences on the drainage of the Stanley Basin and Wood River (Ruppel, 1967). The Lemhi River north of Leadore has been entrenched through what Ruppel calls an "early Pleistocene (?) outwash blanket." The middle section of this river indicates drainage reversal after Pleistocene strike-slip faulting, which gives an approximate upper limiting age for that section of river. The cause of the drainage reversals was the uplift of an arch north of and parallel to the Snake River Plain, as indicated by the low divides in the centers of the affected valleys. This tectonic movement in the early or mid-Pliocene to early Pleistocene (Ross, unpubl.) and the associated drainage changes rejuvenated the Salmon River, which must have sharply increased downcutting throughout its upper reaches and possibly also increased its length through piracy. It is during this episode that the deep valley-cutting in the White Cloud Peaks region took place, giving an upper limiting age of late Pliocene or early Pleistocene for the Railroad Ridge diamicton.

In order to more precisely date the deposition of the Railroad Ridge diamicton, better age relationships of bracketing events or location of fossils or a tephra within the body of the deposit are necessary. A search for such material proved unproductive, with the exception of locating fragments (smaller than 2 cm) of vascular plant material and wood. These were unidentifiable and it is unknown whether they were incorporated during deposition or whether they are remains of later plant roots. Incorporation and preservation of light-weight animal or plant remains by a mudflow would be more likely than by a waterflood, which would tend to carry away any such remains (Bull, 1963). If associated with the deposition of the diamicton, any carbonaceous material would be probably be too old for C^{14} analysis. Lack of tephra beds located within any of the fresh scarps is not unusual since preservation of volcanic ash beds on a fan is a matter of fortuitous timing. Furthermore, the age of the deposit is undoubtedly older than 250,000 years B.P., the outside limit for tephra hydration dating since older samples show considerable to complete superhydration (Steen-McIntyre, 1975). Only a geochemically-identifiable ash would be suitable for a time correlation of the Railroad Ridge diamicton. Pollen analyses may also shed light on climatic conditions and age relations (Richmond et al., 1978).

8 CONCLUSIONS

Several hypotheses have been proposed for the origin of the Railroad Ridge diamicton; these include landslide, rockfall, torrential stream, glaciation, and mudflow (including solifluction). Of these, only the latter two require serious consideration. It is the author's opinion that the fan-building mudflow hypothesis fits the evidence better than the glacial deposit hypothesis. This conclusion is supported by textural data (Figures 8 and 9), discriminant function analysis, the crude stratification visible in fresh diamicton faces (see page 52), the diamicton's thickness and geometry (see page 65), and surface profile (Figure 12) of the deposit. No one piece of evidence favors the glacial hypothesis over the alluvial fan hypothesis. A non-glacial origin is also supported by Madole's (1982) work on diamictons in the Front Range of Colorado, which became available during preparation of the final draft of this document. Working independently, he investigated the geomorphic and sedimentary characteristics of two ridgetop diamictons in the Colorado Front Range and concluded that the deposits were alluvial, colluvial, or debris flow in origin and Tertiary in age.

The investigation of the sedimentological characteristics of the Railroad Ridge diamicton supports a conclusion that the most probable depositional mechanism is mudflow or solifluction and that the diamicton is not of glacial origin as described by previous investigators. Cumulative size percentage plots (Figure 8) of the unweathered Railroad Ridge diamicton samples are slightly displaced towards those of mudflow origin, although they parallel the till samples as well. Use of mean and skewness versus standard deviation plots (Figures 9a and 9b) and Landim and Frakes' (1968) discriminant function analysis, also place the Railroad Ridge diamicton samples in the alluvial fan/mudflow catagory, although they remain marginal to the till grouping. The presence of large boulders in the deposit, thought formerly to be the strongest evidence for a glacial origin, has been shown to be inconclusive due to the competence of fan-building mudflows to carry such large boulders long distances. Furthermore, mudflow deposits are typically unsorted and may greatly resemble glacial till. Since typical alluvial fan facies have not been found in the Railroad Ridge diamicton, a depositional mechanism consisting solely of mudflow or solifluction is hypothesized, although the geometry of the deposit resembles that of an alluvial fan. Currently, no good modern analog of this deposit, to the author's knowledge, exists.

Morphological reconstruction of the ridgetop deposit (Figures 11 and 12) shows that it has the characteristic shape of an alluvial fan at a mountain front. Thicknesses of several hundred feet, as exhibited in the escarpment on "the Spur," are not uncommon for alluvial fans; on the other hand, such thicknesses of glacial ground moraine deposited in a montane setting are rare. The relatively broad and flat surface of the "typical" diamicton, if original, also argues for a fan-building mudflow origin.

Investigation of the provenance of the Railroad Ridge diamicton found only a gross variation of lithologies across the study area (Plates 2 through 6). Metasedimentary lithologies and minerals are relatively common along the northwest side of Railroad Ridge and near the elevated areas on "the Spur" and Red Ridge. Intrusive lithologies and minerals predominate in the southeastern half of the study area. This appears to be a bedrock-related phenomenon in that western Railroad Ridge is composed of metasediments and is adjacent to metasedimentary escarpments which separate it from the White Cloud stock. Extrusive lithologies only appear at the edges of the deposit on Challis Volcanics bedrock, indicating either lack of erosion as the diamicton was transported over large areas of extrusives or that several depositional events took place, mantling and protecting the underlying bedrock from further erosion. Variations of concentrations between pebble and boulder lithologies at the same site can be attributed to differential resistance of those lithologies. The lack of one to one correlation between clast distribution and corresponding heavy mineral concentrations suggests that the matrix is not composed entirely of comminuted incorporated clasts but instead was mixed with clasts from a general source area. If the Railroad Ridge diamicton is a stratified deposit, sample sites in different layers exposed by erosion would also account in part for extreme local variations.

In certain cases, provenance can be used to distinguish the Railroad Ridge diamicton from valley glacial deposits (see page 58). Tills in the lower reaches of Big Boulder Creek have significantly higher metasediment to intrusive clast ratios than does the diamicton on Red Ridge and "Trimline Ridge." Tills of Silver Rule Creek, lower Big Boulder Creek, and Little Boulder Creek contain extrusive clasts; extrusives are generally lacking in the Railroad Ridge diamicton. The diamicton in all areas has relatively high biotite concentrations in the matrix samples while the valley till samples overall have much lower concentrations and lack biotite completely in many cases.

Provenance is incapable of resolving the origin of high gravel deposits along the valley walls of lower Big Boulder Creek (see page 60). Similar deposits along the East Fork of the Salmon River at the mouths of Big Boulder and Little Boulder Creeks appear to be affiliated with the valley tills on the basis of provenance differences noted above. Two patches of diamicton in Silver Rule cirque may also be associated with the valley till on the basis of the presence of extrusive clasts. It is possible that all high gravel deposits lying above or beyond the limits of the latest major glaciation (Figure 3) yet below the ridgetop diamicton can be attributed to an extensive early glaciation. Considering the high altitude of these postulated early glacial deposits in Silver Rule Creek, ice may have topped the low divide into Big Lake Creek, dumping reworked Railroad Ridge diamicton into its headwaters.

A generalized reconstruction of the source area can be developed on the basis of contouring the highest points on the remaining peaks and ridges (Figure 10). Since quartz monzonite is commonly found on Railroad Ridge where there exists no drainage from the stock, material from the ancestral White Cloud Peaks must have drained northeast across "the Spur." Since then, the Livingston Creek drainage has eroded away any remnants of diamicton north and west of Railroad Ridge and Big Boulder Creek has pirated the drainage basin from the east.

Deposition of the diamicton may reflect climatic changes since there is no known evidence for the type of fault-block uplift which characterizes alluvial fan depositional environments in the Basin and Range Province. Possible climatic cooling, due in part to regional uplift over the course of the Pliocene, could account for production of large amounts of bouldery debris by freeze-thaw processes. Formation of bouldery alluvial fans is typical of cold climates rather than hot, arid climates. If the climate was cold, solifluction may have been the major transport mechanism. Associated cryoturbation would account for lack of stratification.

The absolute age of the Railroad Ridge diamicton is unknown. A crude estimate may be made on the basis of geomorphic events surrounding the drift's depostion. Extrusion of the Challis volcanics ended by early Oligocene; this was followed by the development of a planated surface (Figure 13a) composed of coalescing pediments, which are not necessarily time-equivalent. This "pediplain" probably developed over the course of the Miocene. Deposition of the Railroad Ridge diamicton (Figure 13b) began no earlier than the late stages of pedimentation in the White Clouds, since the surface on which it rests has a mature pediment profile. Deposition of the diamicton concluded not later than the onset of valley cutting, an indication of change from a depositional to an erosional regime (Figure 13c). While climatic change may have played a role in initiating downcutting, Ruppel (1967) suggests that diastrophism, beginning in the late Pliocene or early Pleistocene, accounted for significant stream rejuvenation in the study area and throughout central Idaho. The age of the Railroad Ridge diamicton, therefore, is probably Pliocene. More research is needed to increase the accuracy of this estimate. Palynology of the deposit, a search for fossil evidence and tephra, and further study of central Idaho tectonic and climatic changes would be productive areas of research.

If the Railroad Ridge diamicton proves to be a fan-building mudflow deposit, as this study suggests, the origins of the many similar deposits throughout the American Cordillera should be reinvestigated. Deposition by mudflow or solifluction can indicate a different climatic or tectonic regime from that which initiates glaciation. In turn such evidence influences interpretation of late Cenozoic events in the Rocky Mountains and can aid in the study of sedimentologically similar deposits throughout the rest of the world.

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APPENDIX 1: SIZE ANALYSIS DATA

	R R R C		R R R R		R R R S	
PHI SIZE	WEIGHT (g)	%	WEIGHT (g)	%	WEIGHT (g)	%
-1.75	1.348	3.81	2.665	8.05	3.995	13.30
-1.25	1.891	5.34	2.555	7.72	2.621	8.72
-1.00	1.422	4.01	1.024	3.09	1.032	3.44
-0.50	2.062	5.82	1.968	5.95	2.349	7.82
0.00	1.343	3.79	1.203	3.64	1.178	3.92
0.50	2.436	6.88	2.375	7.18	2.676	8.91
1.00	2.038	5.75	1.724	5.21	1.744	5.81
1.50	1.895	5.35	1.628	4.92	1.587	5.28
2.00	2.218	6.26	1.911	5.76	1.610	5.36
2.50	1.380	3.90	0.923	2.79	0.999	3.33
3.00	1.955	5.52	1.152	3.48	1.299	4.32
3.50	2.278	6.43	1.313	3.97	1.560	5.19
4.00	1.923	5.43	1.328	4.01	1.357	4.52
5.00	4.270	12.06	4.120	12.45	2.045	6.81
6.00	2.910	8.22	2.795	8.45	1.415	4.71
7.00	1.390	3.92	1.830	5.53	0.000	0.00
8.00	1.415	4.00	1.265	3.82	1.630	5.43
9.00	0.760	2.15	0.810	2.45	0.400	1.33
10.00	0.485	1.37	0.500	1.51	0.545	1.81

	Sp F1		Sp G1	
PHI SIZE	WEIGHT (g)	%	WEIGHT (g)	%
-1.75	2.414	7.05	0.891	3.08
-1.25	2.663	7.77	1.571	5.44
-1.00	1.503	4.39	0.734	2.54
-0.50	2.996	8.75	1.624	5.26
0.00	1.777	5.19	1.239	4.29
0.50	3.172	9.26	3.038	10.52
1.00	2.236	6.53	3.002	10.39
1.50	1.978	5.78	1.875	6.49
2.00	2.186	6.38	2.917	10.10
2.50	1.329	3.88	1.257	4.35
3.00	1.564	4.57	1.496	5.18
3.50	1.528	4.46	1.652	5.72
4.00	1.250	3.65	1.051	3.64
5.00	2.035	5.94	2.195	7.60
6.00	1.500	4.38	1.185	4.10
7.00	2.175	6.35	1.165	4.03
8.00	0.000	0.00	0.725	2.51
9.00	1.010	2.95	0.620	2.15
10.00	0.935	2.73	0.650	2.25

APPENDIX 2: PROVENANCE DATA, BOULDER LITHOLOGIES

INTRUSIVE LITHOLOGIES

SAMPLE	APLITE #	APLITE %	QUARTZ MONZONITE #	QUARTZ MONZONITE %	VEIN QUARTZ #	VEIN QUARTZ %	BIOTITE ANDESITE #	BIOTITE ANDESITE %	TOTAL INTRUSIVES #	TOTAL INTRUSIVES %
RRR A	1	4	10	40	0	0	0	0	11	44
RRR B	1	4	25	60	0	0	0	0	16	64
RRR C	0	0	16	64	0	0	0	0	16	64
RRR D	0	0	0	0	0	0	0	0	0	0
RRR E	0	0	22	88	0	0	0	0	22	88
RRR F	3	12	11	42	1	4	0	0	15	58
RRR H	1	4	6	24	0	0	0	0	7	28
RRR I	1	4	24	96	0	0	0	0	25	100
RRR J	0	0	25	100	0	0	0	0	25	100
RRR K	1	4	9	36	0	0	0	0	10	40
RRR L	0	0	10	40	1	4	0	0	11	44
RRR M	0	0	22	88	0	0	0	0	22	88
RRR N	0	0	0	0	4	16	0	0	4	16
RRR O	2	8	12	48	0	0	0	0	14	56
RRR P	2	8	6	24	2	8	0	0	10	40
RRR Q	2	8	9	36	0	0	0	0	11	44
Sp A1	0	0	25	100	0	0	0	0	25	100
Sp B1	0	0	3	12	1	4	0	0	4	16
Sp C1	0	0	21	84	0	0	1	4	22	88
Sp D1	0	0	20	80	0	0	0	0	20	80
Sp E1	0	0	25	100	0	0	0	0	25	100
Red A2	0	0	4	16	0	0	0	0	4	16
Red C2	1	4	13	52	0	0	0	0	14	56
Red D2	2	8	22	88	0	0	1	4	25	100
Red E2	1	4	24	96	0	0	0	0	25	100
Red F2	2	8	22	88	0	0	1	4	25	100
Red G2	0	0	25	100	0	0	0	0	25	100
Red H2	10	40	15	60	0	0	0	0	25	100
Red I2	5	20	20	80	0	0	0	0	25	100
Tr A4	6	24	19	76	0	0	0	0	25	100
Tr B4	2	8	23	92	0	0	0	0	25	100
Tr C4	1	4	18	72	1	4	0	0	20	80
Ag A3	0	0	0	0	0	0	0	0	0	0

METASEDIMENT LITHOLOGIES

SAMPLE	GRAY METASEDS. #	GRAY METASEDS. %	BANDED METASEDS. #	BANDED METASEDS. %	LIGHT &/OR CALCAREOUS QUARTZITE #	LIGHT &/OR CALCAREOUS QUARTZITE %	TOTAL METASEDS. #	TOTAL METASEDS. %
RRR A	3	12	7	28	4	16	14	56
RRR B	0	0	7	28	2	8	9	36
RRR C	0	0	3	12	6	24	9	36
RRR D	5	20	1	4	19	76	25	100
RRR E	0	0	1	4	2	8	3	12
RRR F	2	8	0	0	9	35	11	42
RRR H	5	10	0	0	13	52	18	72
RRR I	0	0	0	0	0	0	0	0
RRR J	0	0	0	0	0	0	0	0
RRR K	2	8	0	0	13	52	15	60
RRR L	1	4	0	0	11	44	12	48
RRR M	0	0	0	0	1	4	1	4
RRR N	14	56	0	0	7	28	21	84
RRR O	1	4	0	0	7	28	8	32
RRR P	6	24	0	0	6	24	12	48
RRR Q	5	20	0	0	9	36	14	56
Sp A1	0	0	0	0	0	0	0	0
Sp B1	0	0	21	84	0	0	21	84
Sp C1	1	4	2	8	0	0	3	12
Sp D1	0	0	0	0	5	20	5	20
Sp E1	0	0	0	0	0	0	0	0
Red A2	1	4	0	0	20	80	21	84
Red C2	3	12	0	0	8	32	11	44
Red D2	0	0	0	0	0	0	0	0
Red E2	0	0	0	0	0	0	0	0
Red F2	0	0	0	0	0	0	0	0
Red G2	0	0	0	0	0	0	0	0
Red H2	0	0	0	0	0	0	0	0
Red I2	0	0	0	0	0	0	0	0
Tr A4	0	0	0	0	0	0	0	0
Tr B4	0	0	0	0	0	0	0	0
Tr C4	2	8	0	0	3	12	5	20
Ag A3	0	0	0	0	0	0	0	0

EXTRUSIVE LITHOLOGIES

SAMPLE	CHALLIS VOLCANICS #	CHALLIS VOLCANICS %	CRYPTO-CRYSTALLINE QUARTZ #	CRYPTO-CRYSTALLINE QUARTZ %	TOTAL EXTRUSIVES #	TOTAL EXTRUSIVES %
RRR A	0	0	0	0	0	0
RRR B	0	0	0	0	0	0
RRR C	0	0	0	0	0	0
RRR D	0	0	0	0	0	0
RRR E	0	0	0	0	0	0
RRR F	0	0	0	0	0	0
RRR H	0	0	0	0	0	0
RRR I	0	0	0	0	0	0
RRR J	0	0	0	0	0	0
RRR K	0	0	0	0	0	0
RRR L	2	8	0	0	2	8
RRR M	2	8	0	0	2	8
RRR N	0	0	0	0	0	0
RRR O	3	12	0	0	3	12
RRR P	2	8	1	4	3	12
RRR Q	0	0	0	0	0	0
Sp A1	0	0	0	0	0	0
Sp B1	0	0	0	0	0	0
Sp C1	0	0	0	0	0	0
Sp D1	0	0	0	0	0	0
Sp E1	0	0	0	0	0	0
Red A2	0	0	0	0	0	0
Red C2	0	0	0	0	0	0
Red D2	0	0	0	0	0	0
Red E2	0	0	0	0	0	0
Red F2	0	0	0	0	0	0
Red G2	0	0	0	0	0	0
Red H2	0	0	0	0	0	0
Red I2	0	0	0	0	0	0
Tr A4	0	0	0	0	0	0
Tr B4	0	0	0	0	0	0
Tr C4	0	0	0	0	0	0
Ag A3	25	100	0	0	25	100

APPENDIX 3: PROVENANCE DATA, PEBBLE LITHOLOGIES

INTRUSIVE LITHOLOGIES

SAMPLE	APLITE #	APLITE %	QUARTZ MONZONITE #	QUARTZ MONZONITE %	VEIN QUARTZ #	VEIN QUARTZ %	BIOTITE ANDESITE #	BIOTITE ANDESITE %	TOTAL INTRUSIVES #	TOTAL INTRUSIVES %
RRR A	0	0.0	2	2.0	0	0.0	0	0.0	2	2.0
RRR B	4	3.8	6	5.8	0	0.0	0	0.0	10	9.6
RRR C	1	1.0	30	29.7	0	0.0	0	0.0	31	30.7
RRR D	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
RRR E	14	14.0	36	36.0	3	3.0	0	0.0	53	53.0
RRR F	3	3.0	6	6.1	0	0.0	0	0.0	9	9.1
RRR G	0	0.0	7	7.0	3	3.0	0	0.0	10	10.0
RRR H	5	4.6	11	10.1	0	0.0	0	0.0	16	14.7
RRR I	4	8.0	17	34.0	0	0.0	0	0.0	21	42.0
RRR J	6	11.5	18	34.6	0	0.0	0	0.0	24	46.2
RRR K	2	3.9	3	5.9	0	0.0	0	0.0	5	9.8
RRR L	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
RRR M	3	6.1	2	4.1	0	0.0	0	0.0	5	10.2
RRR O	1	1.8	6	11.1	0	0.0	0	0.0	7	13.0
RRR P	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
RRR Q	3	6.0	8	16.0	0	0.0	0	0.0	11	22.0
RRR R	9	18.0	9	18.0	0	0.0	0	0.0	18	36.0
RRR S	11	21.6	9	17.6	1	2.0	0	0.0	21	41.2
Sp A1	1	2.0	46	92.0	3	6.0	0	0.0	50	100.0
Sp B1	0	0.0	2	4.0	0	0.0	0	0.0	2	4.0
Sp C1	1	2.0	4	8.0	0	0.0	0	0.0	5	10.0
Sp D1	3	6.0	11	22.0	0	0.0	0	0.0	14	28.0
Sp F1	2	4.0	39	78.0	0	0.0	0	0.0	41	82.0
Sp G1	3	6.0	43	86.0	0	0.0	0	0.0	46	92.0
Red A2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Red C2	1	1.8	6	11.1	0	0.0	0	0.0	7	13.0
Red D2	4	6.8	31	52.5	0	0.0	2	3.4	37	62.7
Red E2	5	9.6	33	63.5	2	3.8	1	1.9	41	78.8
Red F2	1	2.0	44	88.0	0	0.0	3	6.0	48	96.0
Red G2	6	10.2	25	43.4	0	0.0	3	5.1	34	57.6
Red H2	5	10.0	41	82.0	0	0.0	0	0.0	46	92.0
Red I2	6	12.0	5	10.0	0	0.0	0	0.0	11	22.0
Tr A4	5	10.0	43	86.0	0	0.0	0	0.0	48	96.0
Tr B4	11	22.0	39	78.0	0	0.0	0	0.0	50	100.0
Tr C4	4	8.0	43	86.0	0	0.0	0	0.0	47	94.0

METASEDIMENT LITHOLOGIES

SAMPLE	GRAY METASEDS. #	GRAY METASEDS. %	BANDED METASEDS. #	BANDED METASEDS. %	LIGHT &/OR CALCAREOUS QUARTZITE #	LIGHT &/OR CALCAREOUS QUARTZITE %	TOTAL METASEDS. #	TOTAL METASEDS. %
RRR A	46	45.5	0	0.0	53	52.5	99	98.0
RRR B	64	61.5	0	0.0	30	28.8	94	90.3
RRR C	12	11.9	0	0.0	58	57.4	70	69.3
RRR D	47	47.5	0	0.0	52	52.5	99	100.0
RRR E	22	22.0	0	0.0	25	25.0	47	47.0
RRR F	53	53.5	0	0.0	37	37.4	90	90.9
RRR G	55	55.0	0	0.0	35	35.0	90	90.0
RRR H	43	39.4	0	0.0	48	44.0	91	83.5
RRR I	14	28.0	2	4.0	13	26.0	29	58.0
RRR J	13	25.0	0	0.0	15	28.8	28	53.8
RRR K	30	58.8	0	0.0	16	31.4	46	90.2
RRR L	3	12.0	0	0.0	3	12.0	6	24.0
RRR M	11	22.4	0	0.0	5	10.2	16	32.6
RRR O	10	18.5	0	0.0	17	31.5	27	50.0
RRR P	7	14.3	0	0.0	10	20.4	17	34.7
RRR Q	23	46.0	0	0.0	16	32.0	39	78.0
RRR R	27	54.0	0	0.0	5	10.0	32	64.0
RRR S	25	49.0	0	0.0	5	9.8	30	58.8
Sp A1	0	0.0	0	0.0	0	0.0	0	0.0
Sp B1	0	0.0	38	76.0	10	20.0	48	96.0
Sp C1	8	16.0	34	68.0	3	6.0	45	90.0
Sp D1	5	10.0	0	0.0	31	62.0	36	72.0
Sp F1	9	18.0	0	0.0	0	0.0	9	18.0
Sp G1	0	0.0	0	0.0	4	8.0	4	8.0
Red A2	9	18.0	0	0.0	41	82.0	50	100.0
Red C2	20	37.0	0	0.0	27	50.0	47	87.0
Red D2	3	5.1	0	0.0	19	32.2	22	37.3
Red E2	2	3.8	0	0.0	9	17.3	11	21.2
Red F2	1	2.0	0	0.0	1	2.0	2	4.0
Red G2	14	23.7	0	0.0	10	17.0	24	40.7
Red H2	3	6.0	0	0.0	1	2.0	4	8.0
Red I2	34	68.0	0	0.0	5	10.0	39	78.0
Tr A4	0	0.0	0	0.0	1	2.0	1	2.0
Tr B4	0	0.0	0	0.0	0	0.0	0	0.0
Tr C4	1	2.0	0	0.0	2	4.0	3	6.0

EXTRUSIVE LITHOLOGIES

SAMPLE	CHALLIS VOLCANICS		CRYPTO-CRYSTALLINE QUARTZ		TOTAL EXTRUSIVES	
	#	%	#	%	#	%
RRR A	0	0.0	0	0.0	0	0.0
RRR B	0	0.0	0	0.0	0	0.0
RRR C	0	0.0	0	0.0	0	0.0
RRR D	0	0.0	0	0.0	0	0.0
RRR E	0	0.0	0	0.0	0	0.0
RRR F	0	0.0	0	0.0	0	0.0
RRR G	0	0.0	0	0.0	0	0.0
RRR H	2	1.8	0	0.0	2	1.8
RRR I	0	0.0	0	0.0	0	0.0
RRR J	0	0.0	0	0.0	0	0.0
RRR K	0	0.0	0	0.0	0	0.0
RRR L	19	76.0	0	0.0	19	76.0
RRR M	28	57.1	0	0.0	28	57.1
RRR O	20	37.0	0	0.0	20	37.0
RRR P	32	65.3	0	0.0	32	65.3
RRR Q	0	0.0	0	0.0	0	0.0
RRR R	0	0.0	0	0.0	0	0.0
RRR S	0	0.0	0	0.0	0	0.0
Sp A1	0	0.0	0	0.0	0	0.0
Sp B1	0	0.0	0	0.0	0	0.0
Sp C1	0	0.0	0	0.0	0	0.0
Sp D1	0	0.0	0	0.0	0	0.0
Sp F1	0	0.0	0	0.0	0	0.0
Sp G1	0	0.0	0	0.0	0	0.0
Red A2	0	0.0	0	0.0	0	0.0
Red C2	0	0.0	0	0.0	0	0.0
Red D2	0	0.0	0	0.0	0	0.0
Red E2	0	0.0	0	0.0	0	0.0
Red F2	0	0.0	0	0.0	0	0.0
Red G2	1	1.7	0	0.0	1	1.7
Red H2	0	0.0	0	0.0	0	0.0
Red I2	0	0.0	0	0.0	0	0.0
Tr A4	1	2.0	0	0.0	1	2.0
Tr B4	0	0.0	0	0.0	0	0.0
Tr C4	0	0.0	0	0.0	0	0.0

APPENDIX 4: PROVENANCE DATA, HEAVY MINERAL SPECIES (WITH ALTERITES)

	MINERAL SPECIES							
	BIOTITE		OPAQUES		DIOPSIDE		TREMOLITE	
SAMPLE	#	%	#	%	#	%	#	%
RRR A	16	5.3	14	4.7	74	24.7	70	23.3
RRR B	13	4.3	5	1.7	35	11.7	190	63.3
RRR C	113	37.7	16	5.3	71	23.7	19	6.3
RRR D	3	1.0	7	2.3	117	39.0	30	10.0
RRR E	59	9.7	9	3.0	96	32.0	4	1.3
RRR F	41	13.7	8	2.7	104	34.7	36	12.0
RRR G	26	8.7	17	5.7	113	37.7	32	10.7
RRR H	39	13.0	7	2.3	95	31.7	48	16.0
RRR I	87	29.0	25	8.3	80	26.7	14	4.7
RRR J	112	37.3	56	18.7	52	17.3	3	1.0
RRR K	95	31.7	11	3.7	75	25.0	14	4.7
RRR L	49	16.3	35	11.7	17	5.7	2	0.7
RRR M	80	26.7	19	6.3	52	17.3	4	1.3
RRR O	56	18.7	40	13.3	23	7.7	1	0.3
RRR P	53	17.7	89	29.7	27	9.0	28	9.3
RRR Q	49	16.3	26	8.7	85	28.3	16	5.3
RRR R	32	10.7	11	3.7	125	41.7	5	1.7
RRR S	77	25.7	25	8.3	72	24.0	21	7.0
Sp A1	272	90.7	4	1.3	0	0.0	1	0.3
Sp B1	122	40.7	8	2.7	66	33.0	20	6.7
Sp C1	181	60.3	21	7.0	24	8.0	15	5.0
Sp D1	199	66.3	20	6.7	24	8.0	0	0.0
Sp E1	43	14.3	123	41.0	24	8.0	1	0.3
Sp F1	173	57.7	69	23.0	0	0.0	0	0.0
Sp G1	56	18.7	184	61.3	1	0.3	4	1.7
Red A2	2	0.7	82	27.3	67	22.3	3	1.0
Red B2L	2	0.7	25	8.3	83	27.7	1	0.3
Red B2U	19	6.3	17	5.7	65	21.7	2	0.7
Red C2	60	20.0	27	9.0	83	27.7	35	11.7
Red D2	19	6.3	89	29.7	79	26.3	0	0.0
Red E2	120	40.0	95	31.7	22	7.3	4	1.3
Red F2	193	64.3	56	18.7	0	0.0	0	0.0
Red G2	113	37.7	50	16.7	79	26.3	5	1.7
Red H2	87	29.0	91	30.3	0	0.0	3	1.0
Red I2	49	16.3	61	20.3	66	22.0	5	1.7
Tr A4	200	66.7	51	17.0	0	0.0	0	0.0
Tr B4	120	40.0	102	34.0	2	0.7	1	0.3
Tr C4	128	42.7	109	36.3	0	0.0	0	0.0

MINERAL SPECIES (CONTINUED)

SAMPLE	AUGITE #	AUGITE %	HORNBLENDE #	HORNBLENDE %	MUSCOVITE #	MUSCOVITE %	CHLORITE #	CHLORITE %
RRR A	3	1.0	2	0.7	3	1.0	0	0.0
RRR B	0	0.0	1	0.3	6	2.0	1	0.3
RRR C	8	2.7	7	2.3	16	5.3	1	0.3
RRR D	1	0.3	0	0.0	6	2.0	0	0.0
RRR E	5	1.7	2	0.7	23	7.7	5	1.7
RRR F	0	0.0	6	2.0	5	1.7	1	0.3
RRR G	6	2.0	11	3.7	8	2.7	2	0.7
RRR H	0	0.0	3	1.0	7	2.3	6	2.0
RRR I	5	1.7	0	0.0	9	3.0	9	3.0
RRR J	3	1.0	1	0.3	7	2.3	13	4.3
RRR K	1	0.3	3	1.0	9	3.0	4	1.3
RRR L	108	36.0	60	20.0	3	1.0	0	0.0
RRR M	98	32.7	4	1.3	7	2.3	5	1.7
RRR O	125	41.7	9	3.0	14	4.7	2	0.7
RRR P	5	1.7	4	1.3	11	3.7	0	0.0
RRR Q	1	0.3	1	0.3	18	6.0	3	1.0
RRR R	0	0.0	2	0.7	5	1.7	1	0.3
RRR S	2	0.7	2	0.7	9	3.0	6	2.0
Sp A1	0	0.0	1	0.3	7	2.3	0	0.0
Sp B1	0	0.0	3	1.0	22	7.3	4	1.3
Sp C1	0	0.0	2	0.7	19	6.3	3	1.0
Sp D1	0	0.0	1	0.3	11	3.7	12	4.0
Sp E1	18	6.0	9	3.0	42	14.0	3	1.0
Sp F1	0	0.0	0	0.0	19	6.3	5	1.7
Sp G1	0	0.0	10	3.3	13	4.3	2	0.7
Red A2	55	18.3	11	3.7	17	5.7	0	0.0
Red B2L	117	39.0	20	6.7	4	1.3	0	0.0
Red B2U	98	32.7	20	6.7	4	1.3	2	0.7
Red C2	1	0.3	9	3.0	15	5.0	1	0.3
Red D2	1	0.3	46	15.3	16	5.3	6	2.0
Red E2	0	0.0	17	5.7	13	4.3	2	0.7
Red F2	0	0.0	22	7.3	18	6.0	0	0.0
Red G2	1	0.3	12	4.0	10	3.3	4	1.3
Red H2	0	0.0	89	29.7	14	4.7	0	0.0
Red I2	4	1.3	15	5.0	5	1.7	7	2.3
Tr A4	1	0.3	28	9.3	4	1.3	1	0.3
Tr B4	1	0.3	41	13.7	12	4.0	0	0.0
Tr C4	2	0.7	1	0.3	15	5.0	3	1.0

MINERAL SPECIES (CONTINUED)

SAMPLE	APATITE #	APATITE %	SPHENE #	SPHENE %	ISOTROPICS #	ISOTROPICS %	ALTERITES #	ALTERITES %
RRR A	0	0.0	1	0.3	0	0.0	117	39.0
RRR B	0	0.0	1	0.3	1	0.3	47	15.7
RRR C	9	3.0	11	3.7	0	0.0	29	9.7
RRR D	0	0.0	1	0.3	0	0.0	135	45.0
RRR E	13	4.3	8	2.7	1	0.3	75	25.0
RRR F	0	0.0	7	2.3	0	0.0	92	30.7
RRR G	7	2.3	3	1.0	0	0.0	75	25.0
RRR H	7	2.3	6	2.0	1	0.3	81	27.0
RRR I	12	4.0	5	1.7	0	0.0	54	18.0
RRR J	12	4.0	11	3.7	0	0.0	30	10.0
RRR K	8	2.7	11	3.7	0	0.0	69	23.0
RRR L	3	1.0	1	0.3	0	0.0	22	7.3
RRR M	2	0.7	6	2.0	0	0.0	23	7.7
RRR O	4	1.3	2	0.7	1	0.3	23	7.7
RRR P	6	2.0	7	2.3	6	2.0	64	21.3
RRR Q	5	1.7	4	1.3	1	0.3	91	30.3
RRR R	11	3.7	0	0.0	0	0.0	108	36.0
RRR S	12	4.0	6	2.0	0	0.0	68	22.7
Sp A1	6	2.0	7	2.3	0	0.0	2	0.7
Sp B1	9	3.0	7	2.3	1	0.3	38	12.7
Sp C1	2	0.7	11	3.7	0	0.0	22	7.3
Sp D1	10	3.3	1	0.3	0	0.0	22	7.3
Sp E1	10	3.3	4	1.3	1	0.3	22	7.3
Sp F1	13	4.3	8	2.7	0	0.0	13	4.3
Sp G1	16	5.3	8	2.7	0	0.0	6	2.0
Red A2	1	0.3	4	1.3	3	1.0	55	18.3
Red B2L	0	0.0	0	0.0	0	0.0	48	16.0
Red B2U	7	2.3	3	1.0	1	0.3	62	20.7
Red C2	26	8.7	4	1.3	9	3.0	30	10.0
Red D2	20	6.7	3	1.0	3	1.0	18	6.0
Red E2	15	5.0	3	1.0	0	0.0	9	3.0
Red F2	6	2.0	2	0.7	0	0.0	3	1.0
Red G2	9	3.0	3	1.0	1	0.3	13	4.3
Red H2	9	3.0	1	0.3	1	0.3	5	1.7
Red I2	14	4.7	1	0.3	2	0.7	71	23.7
Tr A4	14	4.7	0	0.0	1	0.3	0	0.0
Tr B4	13	4.3	2	0.7	1	0.3	5	1.7
Tr C4	14	4.7	7	2.3	0	0.0	21	7.0

APPENDIX 5: PROVENANCE DATA, HEAVY MINERAL SPECIES (WITHOUT ALTERITES)

MINERAL SPECIES

SAMPLE	BIOTITE #	BIOTITE %	OPAQUES #	OPAQUES %	DIOPSIDE #	DIOPSIDE %	TREMOLITE #	TREMOLITE %
RRR A	24	8.0	21	7.0	120	40.0	121	40.3
RRR B	14	4.7	6	2.0	39	13.0	228	76.0
RRR C	121	40.3	21	7.0	81	27.0	19	6.3
RRR D	7	2.3	12	4.0	220	73.3	47	15.7
RRR E	81	27.0	12	4.0	132	44.0	4	1.3
RRR F	58	19.3	8	2.7	142	47.3	58	19.3
RRR G	36	12.0	24	8.0	141	47.0	44	14.7
RRR H	44	14.7	13	4.3	136	45.3	65	21.7
RRR I	119	39.7	26	8.7	94	31.3	17	5.7
RRR J	118	39.3	62	20.7	60	20.0	3	1.0
RRR K	124	41.3	12	4.0	98	32.7	17	5.7
RRR L	50	16.7	41	13.7	17	5.7	3	1.0
RRR M	86	28.7	21	7.0	58	19.3	6	2.0
RRR O	59	19.7	43	14.3	27	9.0	1	0.3
RRR P	67	22.3	112	37.3	32	10.7	36	12.0
RRR Q	80	26.7	31	10.3	120	40.0	29	9.7
RRR R	50	16.7	21	7.0	196	65.3	8	2.7
RRR S	101	33.7	37	12.3	92	30.7	23	7.7
Sp A1	274	91.3	4	1.3	0	0.0	1	0.3
Sp B1	139	46.3	8	2.7	76	25.3	25	8.3
Sp C1	194	64.7	23	7.7	24	8.0	17	5.7
Sp D1	207	69.0	23	7.7	28	9.3	0	0.0
Sp E1	46	15.3	132	44.0	27	9.0	1	0.3
Sp F1	184	61.3	70	23.3	0	0.0	0	0.0
Sp G1	56	18.7	190	63.3	1	0.3	4	1.3
Red A2	3	1.0	101	33.7	83	27.7	3	1.0
Red B2L	2	0.7	26	8.7	93	31.0	1	0.3
Red B2U	22	7.3	21	7.0	85	28.3	2	0.7
Red C2	67	22.3	29	9.7	95	31.7	39	13.0
Red D2	22	7.3	95	31.7	82	27.3	0	0.0
Red E2	124	41.2	96	32.0	24	8.0	4	1.3
Red F2	195	65.0	56	18.7	0	0.0	0	0.0
Red G2	120	40.0	51	17.0	81	27.0	5	1.7
Red H2	87	29.0	92	30.7	0	0.0	3	1.0
Red I2	60	20.0	79	26.3	90	30.0	7	2.3
Tr A4	200	66.7	51	17.0	0	0.0	0	0.0
Tr B4	120	40.0	105	35.0	2	0.7	1	0.3
Tr C4	138	46.0	117	39.0	0	0.0	0	0.0

MINERAL SPECIES (CONTINUED)

SAMPLE	AUGITE #	AUGITE %	HORNBLENDE #	HORNBLENDE %	MUSCOVITE #	MUSCOVITE %	CHLORITE #	CHLORITE %
RRR A	4	1.3	3	1.0	4	1.3	0	0.0
RRR B	1	0.3	1	0.3	6	2.0	2	0.7
RRR C	9	3.0	7	2.3	17	5.7	1	0.3
RRR D	0	0.0	0	0.0	9	3.0	0	0.0
RRR E	6	2.0	4	1.3	31	10.3	6	2.0
RRR F	3	1.0	7	2.3	9	3.0	1	0.3
RRR G	8	2.7	16	5.3	12	4.0	3	1.0
RRR H	3	1.0	3	1.0	10	3.3	7	2.3
RRR I	5	1.7	0	0.0	9	3.0	10	3.3
RRR J	4	1.3	1	0.3	8	2.7	14	4.7
RRR K	1	0.3	5	1.7	12	4.0	5	1.7
RRR L	118	39.3	64	21.3	3	1.0	0	0.0
RRR M	104	34.7	4	1.3	7	2.3	6	2.0
RRR O	136	45.3	10	3.3	14	4.7	2	0.7
RRR P	5	2.7	6	2.0	14	4.7	0	0.0
RRR Q	1	0.3	1	0.3	20	6.7	3	1.0
RRR R	0	0.0	2	0.7	8	2.7	2	0.7
RRR S	2	0.7	3	1.0	16	5.3	6	2.0
Sp A1	0	0.0	1	0.3	7	2.3	0	0.0
Sp B1	0	0.0	6	2.0	23	7.7	5	1.7
Sp C1	0	0.0	2	0.7	23	7.7	3	1.0
Sp D1	0	0.0	1	0.3	13	4.3	12	4.0
Sp E1	21	7.0	9	3.0	44	14.7	3	1.0
Sp F1	0	0.0	0	0.0	20	6.7	5	1.7
Sp G1	0	0.0	10	3.3	13	4.3	2	0.7
Red A2	65	21.7	15	5.0	22	7.3	0	0.0
Red B2L	146	48.7	27	9.0	5	1.7	0	0.0
Red B2U	127	42.3	25	8.3	4	1.3	2	0.7
Red C2	1	0.3	9	3.0	16	5.3	1	0.3
Red D2	1	0.3	50	16.7	17	5.7	7	2.3
Red E2	1	0.3	17	5.7	14	4.7	2	0.7
Red F2	0	0.0	22	7.3	19	6.3	0	0.0
Red G2	1	0.3	12	4.0	10	3.3	4	1.3
Red H2	0	0.0	92	30.7	15	5.0	0	0.0
Red I2	4	1.3	16	5.3	8	2.7	13	4.3
Tr A4	1	0.3	28	9.3	4	1.3	1	0.3
Tr B4	1	0.3	43	14.3	12	4.0	0	0.0
Tr C4	3	1.0	1	0.3	16	5.3	3	1.0

MINERAL SPECIES (CONTINUED)

SAMPLE	APATITE #	APATITE %	SPHENE #	SPHENE %	ISOTROPICS #	ISOTROPICS %
RRR A	1	0.3	1	0.3	1	0.3
RRR B	1	0.3	1	0.3	1	0.3
RRR C	13	4.3	11	3.7	0	0.0
RRR D	2	0.7	2	0.7	1	0.3
RRR E	14	4.7	9	3.0	1	0.3
RRR F	2	0.7	12	4.0	0	0.0
RRR G	10	3.3	6	2.0	0	0.0
RRR H	9	3.0	9	3.0	1	0.3
RRR I	13	4.3	7	2.3	0	0.0
RRR J	19	6.3	11	3.7	0	0.0
RRR K	11	3.7	15	5.0	0	0.0
RRR L	3	1.0	1	0.3	0	0.0
RRR M	2	0.7	0	0.0	0	0.0
RRR O	5	1.7	2	0.7	1	0.3
RRR P	10	3.3	11	3.7	7	2.3
RRR Q	7	2.3	4	1.3	4	1.3
RRR R	13	4.3	0	0.0	0	0.0
RRR S	14	4.7	6	2.0	0	0.0
Sp A1	6	2.0	7	2.3	0	0.0
Sp B1	10	3.3	7	2.3	1	0.3
Sp C1	2	0.7	12	4.0	0	0.0
Sp D1	15	5.0	1	0.3	0	0.0
Sp E1	11	3.7	5	1.7	1	0.3
Sp F1	13	4.3	8	2.7	0	0.0
Sp G1	16	5.3	8	2.7	0	0.0
Red A2	1	0.3	4	1.3	3	1.0
Red B2L	0	0.0	0	0.0	0	0.0
Red B2U	8	2.7	3	1.0	1	0.3
Red C2	29	9.7	4	1.3	10	3.3
Red D2	20	6.7	3	1.0	3	1.0
Red E2	15	5.0	3	1.0	0	0.0
Red F2	6	2.0	2	0.7	0	0.0
Red G2	11	3.7	3	1.0	2	0.7
Red H2	9	3.0	1	0.3	1	0.3
Red I2	19	6.3	2	0.7	2	0.7
Tr A4	14	4.7	0	0.0	1	0.3
Tr B4	13	4.3	2	0.7	1	0.3
Tr C4	15	5.0	7	2.3	0	0.0

VITA

Susan Lynn Gawarecki

Born: Bethesda, Md., Feb. 18, 1957

Parents: Dr. Stephen J. Gawarecki
Carolyn A. Grosse Gawarecki

Married:
Jan. 6, 1980, to Stephen Kenneth Perry

Academic training:

1970-1974	Falls Church High School Falls Church, Va.
1974-1978	University of Virginia Charlottesville, Va Echols Scholar B.A. Environmental Science (1978)
1978-1981	Lehigh University Bethlehem, Pa. M.S. Geological Sciences (1983)
1981-present	University of South Carolina Columbia, SC Ph.D. Geology (in preparation)

Awards:
Sigma Xi Grant-in-Aid of Research, 1979
J. Hoover Mackin Research Grant, 1980
N.S.F. Fellowship, Univ. of South Carolina Egyptian Project (1981, 1982, 1983)

Membership, professional organizations:
Sigma Gamma Epsilon
Sigma Xi
Canadian Quaternary Association (CANQUA)
American Society of Photogrammetry (ASP)

Poster session:
title: ICE S.T.R.E.A.M. (ICE: A Systematic Technique for Rapid Exploration and Assessment of Mineralization) A Cooperative U.S.G.S. - Lehigh Project
co-author: Dr. Edward B. Evenson
for: Glacial Geology in the Service of Mineral Exploration: A Workshop
Dept. of Geology, Univ. of Toronto
April, 1980

Reports and Maps:

title: LANDSAT Imagery Study of Iraq
LANDSAT Map of Iraq
Lineament and Anomaly Map of Iraq
for: Amoco International
prepared at: Earth Resources and Sciences Institute
September, 1981

title: Neotectonic Evolution of the Northern North Amer
Concession Area, Gulf of Suez, Egypt
co-author: Stephen K. Perry
for: Louisiana Land & Exploration, Ltd.
prepared at: Earth Sciences and Resources Institute
September, 1982

Articles:

title: The Railroad Ridge Diamicton: A Relict Fan Complex
Formerly Considered Glacial Till
co-author: Dr. Edward B. Evenson
for: INQUA Special Volume
(in progress)

title: Paleomagnetic Studies on the Perdicca Elephant Section
Sediments, Northern Greece: Preliminary Data
co-authors: Dr. A.E.M. Nairn, S.K. Perry, Dr. A.N. Poulianos
for: "Anthropos," Journal of the Anthropological Association
of Greece
(in press)

Professional Employment:

1977-1978	Research Assistant, U.Va. Wind Energy Project
1978	Field Assistant, Lehigh Univ. Idaho Quaternary Mapping Project
1978-1979	Teaching Assistant, Lehigh Univ. Dept. of Geological Sciences
1979	Teaching Assistant, Lehigh Univ. Geology Field Camp
1979-1980	Teaching Assistant, Lehigh Univ.. Dept. of Geological Sciences
1980	Research Assistant, Lehigh Univ. Pa. D.E.R. Groundwater Evaluation Project
1980	Field Assistant, U.S.G.S. Geochemical Evaluation of Mt. Hayes Quad., Alaska
1980	Teaching Assistant, Lehigh Univ. Dept. of Geological Sciences
1981-1983	Research Assistant, Univ. of South Carolina Earth Sciences and Resources Institute

Current Position:

Ph.D. Candidate
Research Assistant
Earth Sciences and Resources Institute
Department of Geology
University of South Carolina
Columbia, S.C. 29208

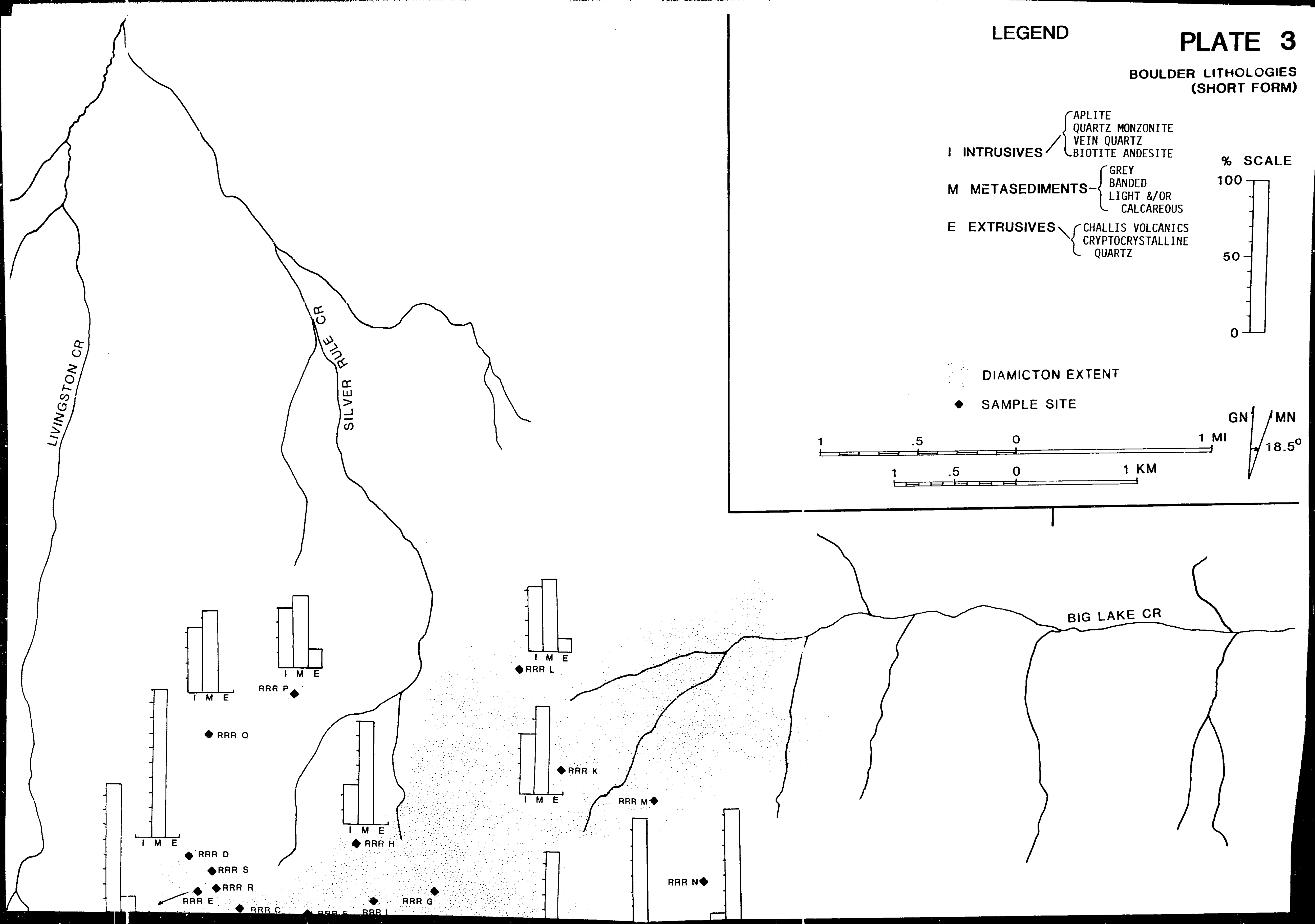
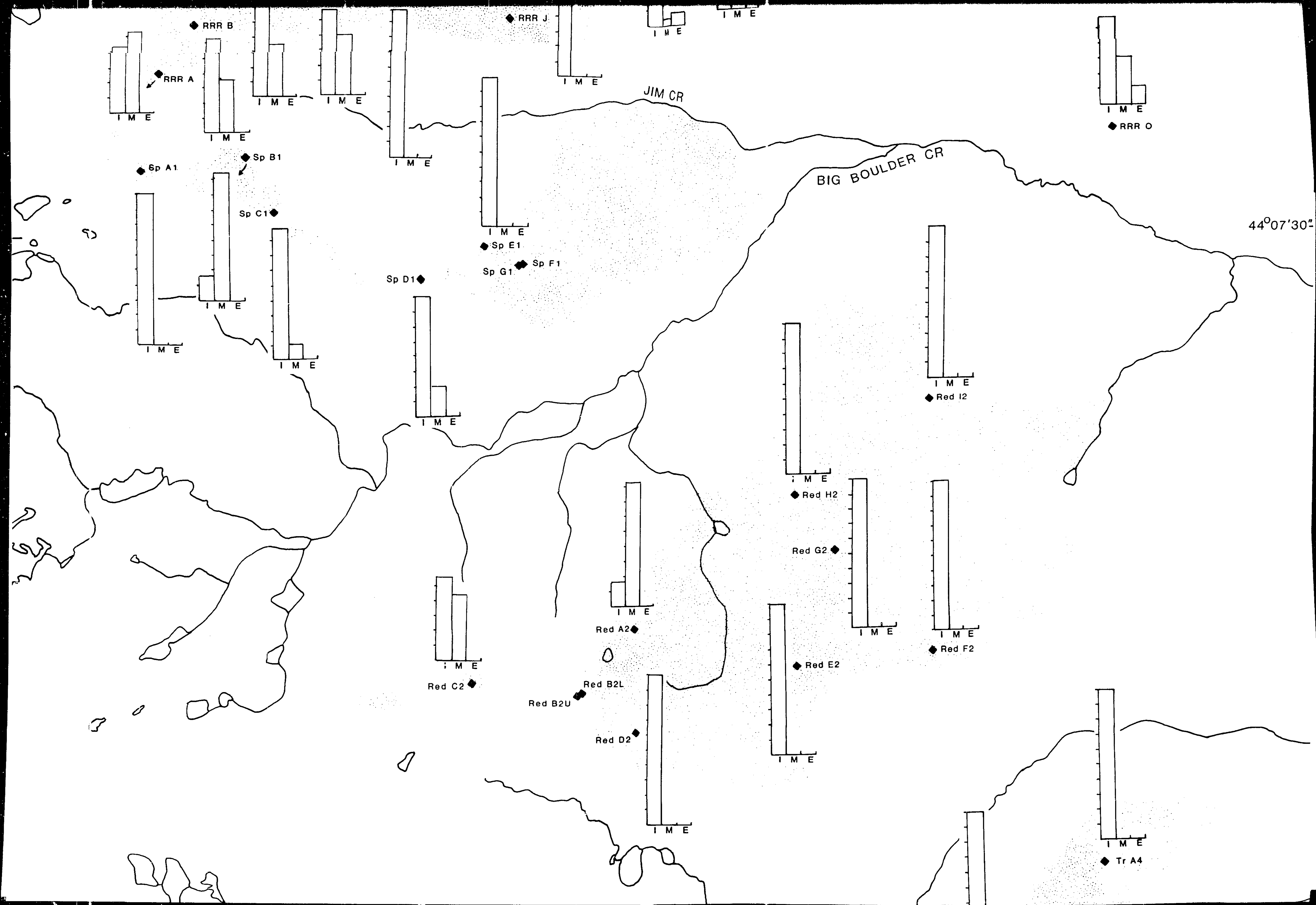
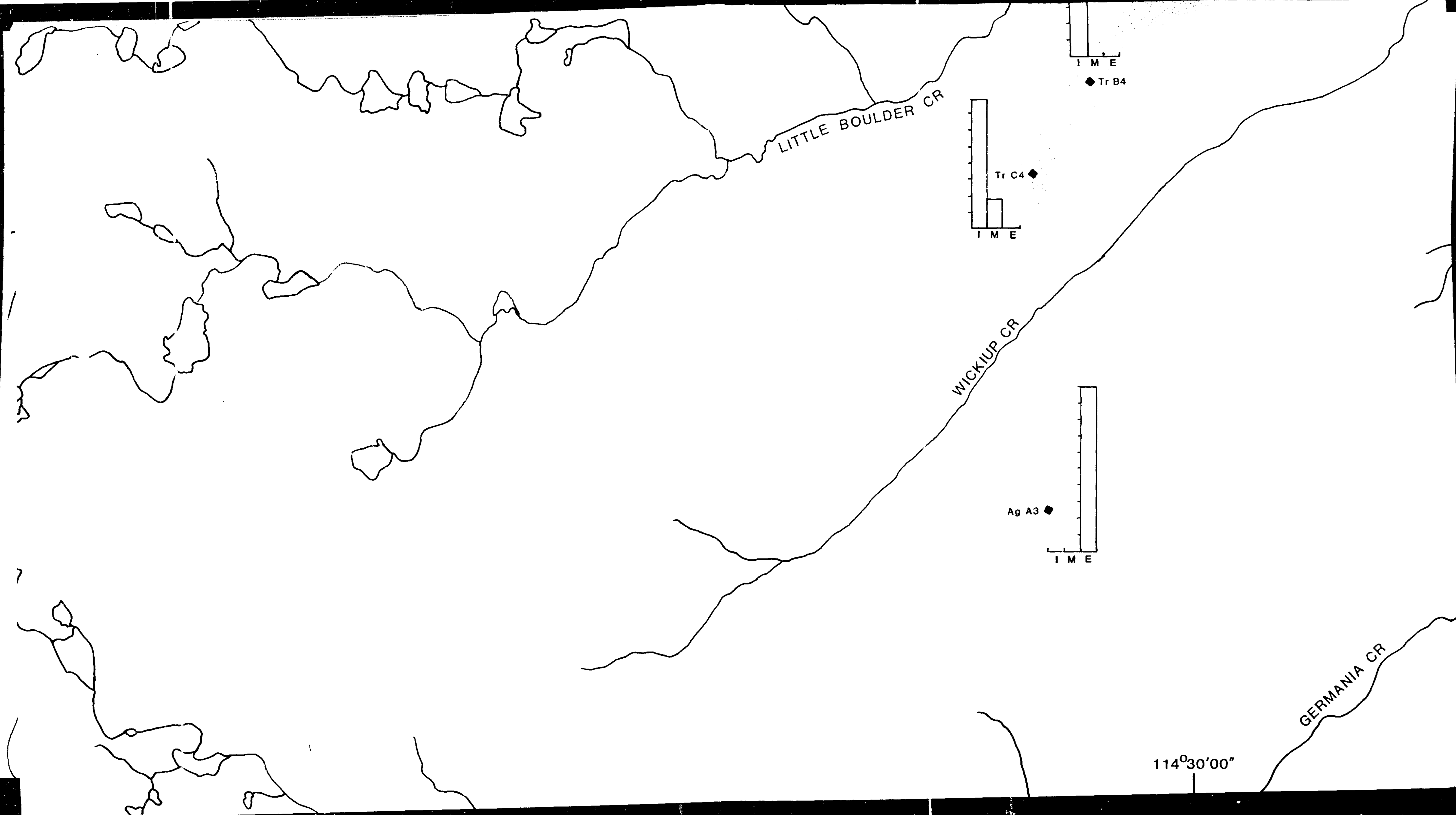


PLATE 3
BOULDER LITHOLOGIES
(SHORT FORM)
LEGEND
I INTRUSIVES
APLITE
QUARTZ MONZONITE
VEIN QUARTZ
BIOTITE ANDESITE
M METASEDIMENTS
GREY
BANDED
LIGHT &/OR
CALCAREOUS
E EXTRUSIVES
CHALLIS VOLCANICS
CRYPTOCRYSTALLINE
QUARTZ
% SCALE
100
50
0
DIAMICTON EXTENT
SAMPLE SITE
GN
MN
18.5°
1 .5 0 1 MI
1 .5 0 1 KM
LIVINGSTON CR
SILVER RULE CR
BIG LAKE CR
RRR P
RRR Q
RRR L
RRR K
RRR M
RRR N
RRR H
RRR D
RRR S
RRR R
RRR E
RRR G
I M E


JIM CR
BIG BOULDER CR
44°07'30"
RRR A
RRR B
RRR J
RRR O
Sp A1
Sp B1
Sp C1
Sp D1
Sp E1
Sp F1
Sp G1
Red A2
Red B2L
Red B2U
Red C2
Red D2
Red E2
Red F2
Red G2
Red H2
Red I2
Tr A4
I M E



LITTLE BOULDER CR
WICKIUP CR
GERMANIA CR
Tr B4
I M E
Tr C4
I M E
Ag A3
I M E
114°30'00"

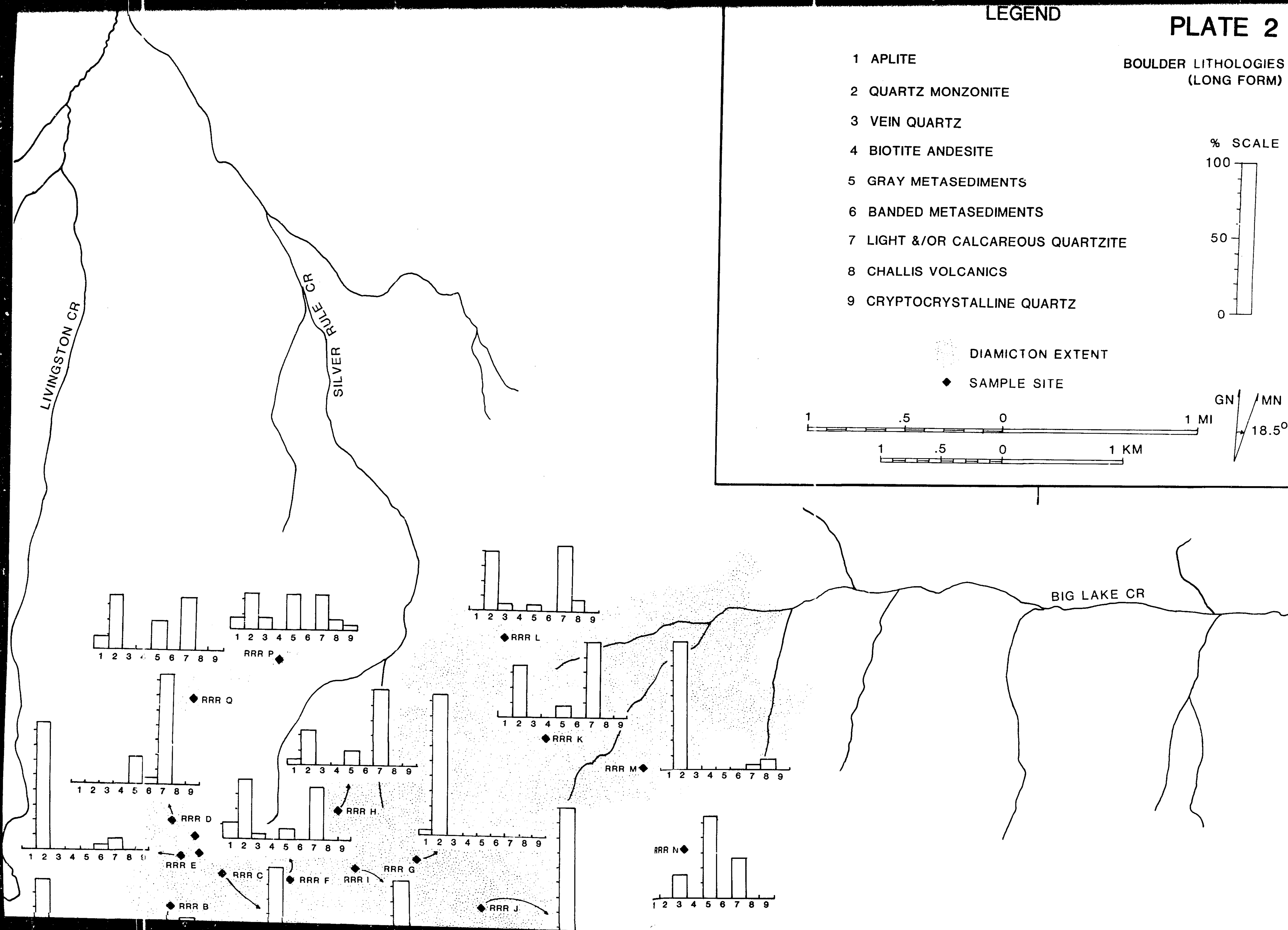
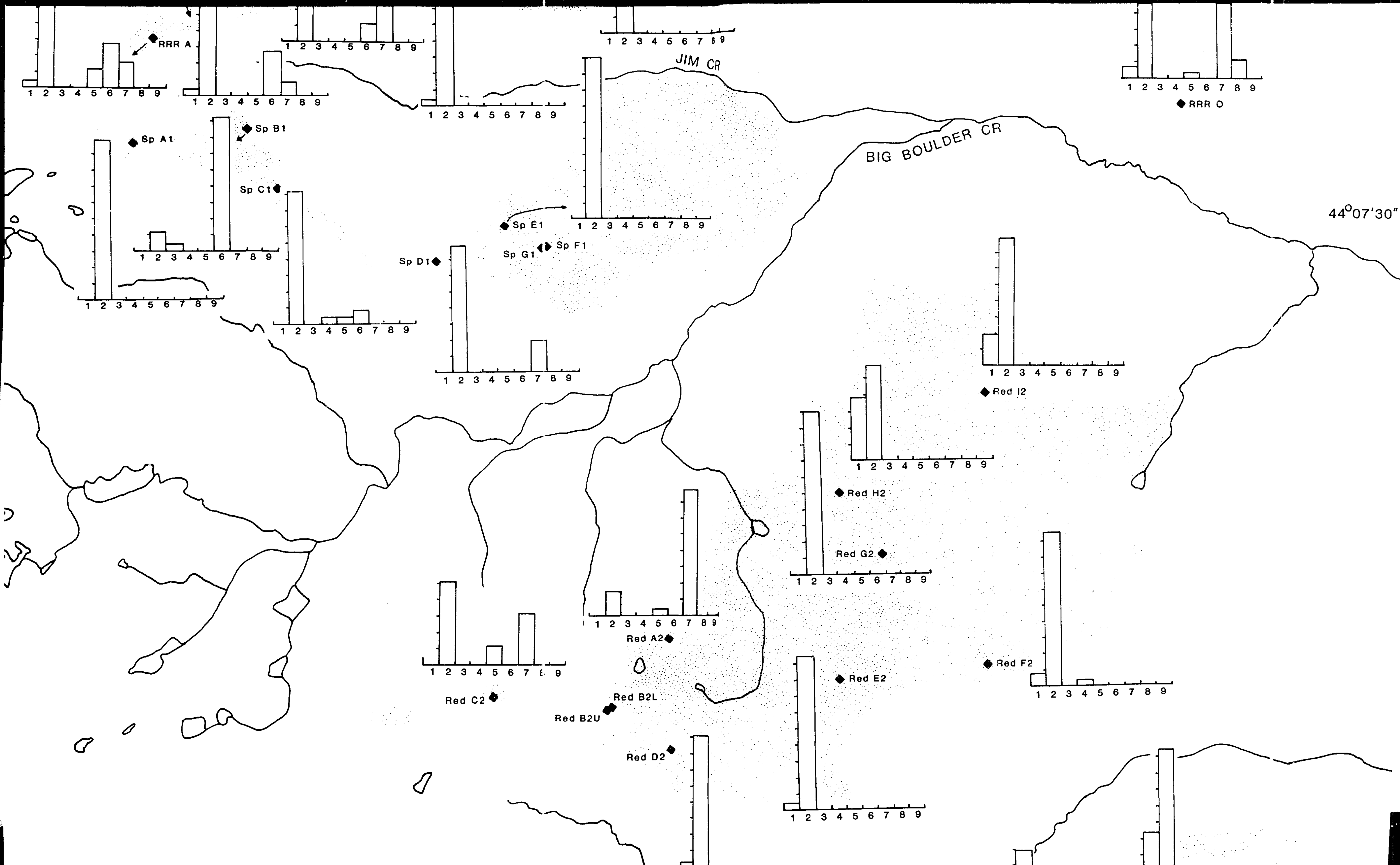
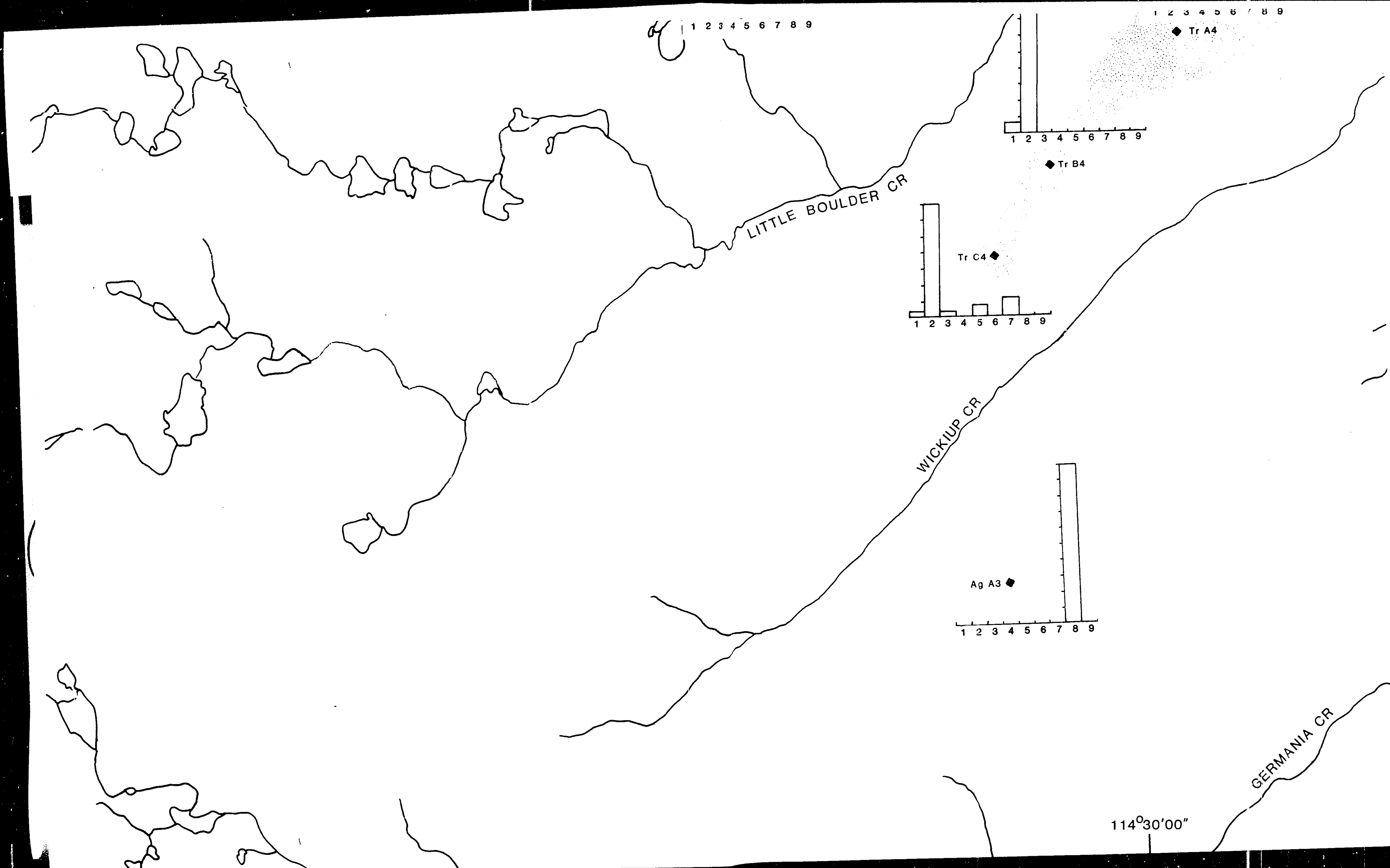


PLATE 2
BOULDER LITHOLOGIES
(LONG FORM)
LEGEND
1 APLITE
2 QUARTZ MONZONITE
3 VEIN QUARTZ
4 BIOTITE ANDESITE
5 GRAY METASEDIMENTS
6 BANDED METASEDIMENTS
7 LIGHT &/OR CALCAREOUS QUARTZITE
8 CHALLIS VOLCANICS
9 CRYPTOCRYSTALLINE QUARTZ
% SCALE
100
50
0
DIAMICTON EXTENT
SAMPLE SITE
1 .5 0 1 MI
1 .5 0 1 KM
GN
MN
18.5°
LIVINGSTON CR
SILVER RULE CR
BIG LAKE CR
RRR B
RRR C
RRR D
RRR E
RRR F
RRR G
RRR H
RRR I
RRR J
RRR K
RRR L
RRR M
RRR N
RRR P
RRR Q



JIM CR
BIG BOULDER CR
44°07'30"
RRR A
RRR O
Sp A1
Sp B1
Sp C1
Sp D1
Sp E1
Sp F1
Sp G1
Red A2
Red B2L
Red B2U
Red C2
Red D2
Red E2
Red F2
Red G2
Red H2
Red I2



LITTLE BOULDER CR
WICKIUP CR
GERMANIA CR
114°30'00"
Tr A4
Tr B4
Tr C4
Ag A3
1 2 3 4 5 6 7 8 9

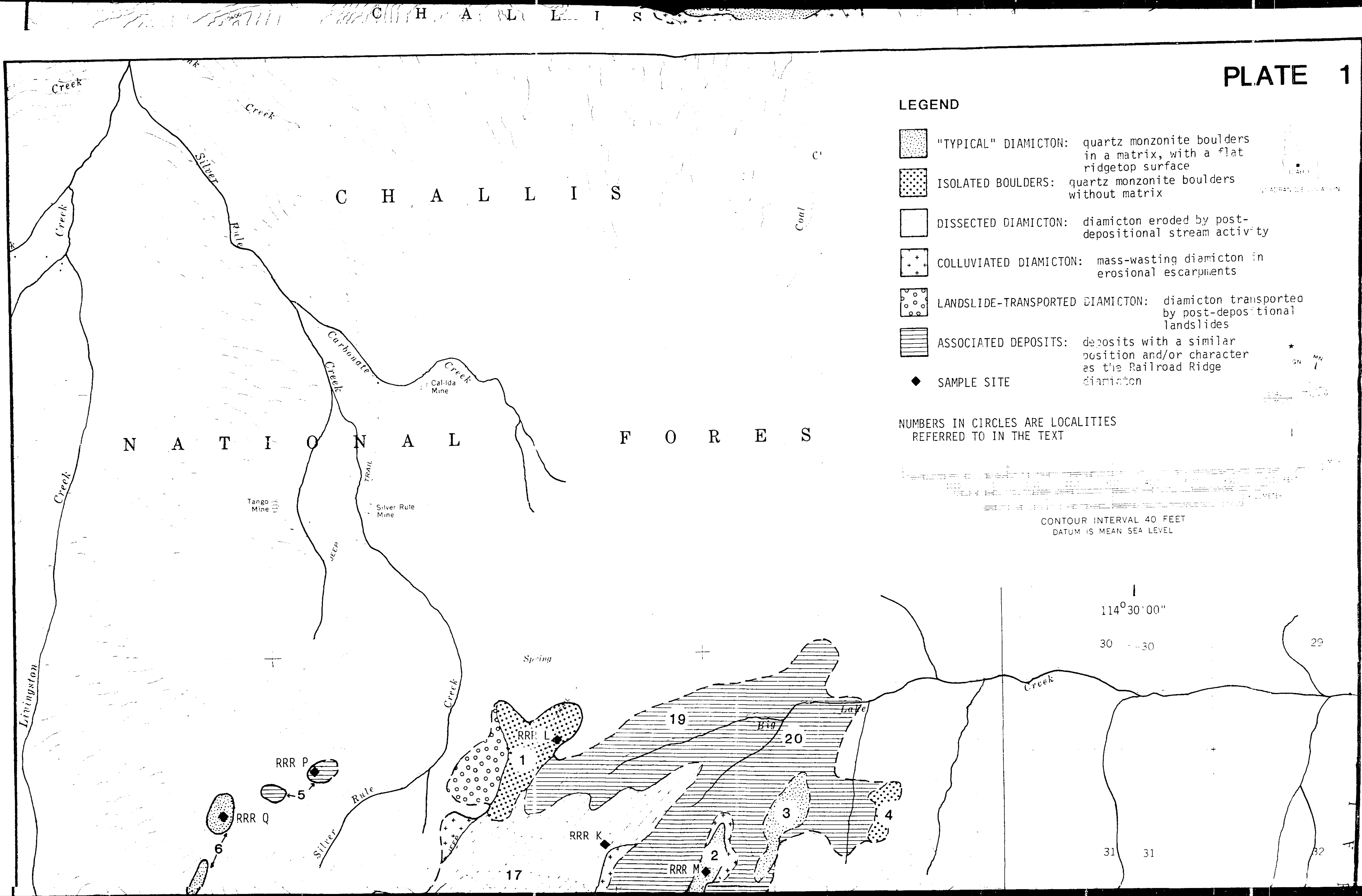
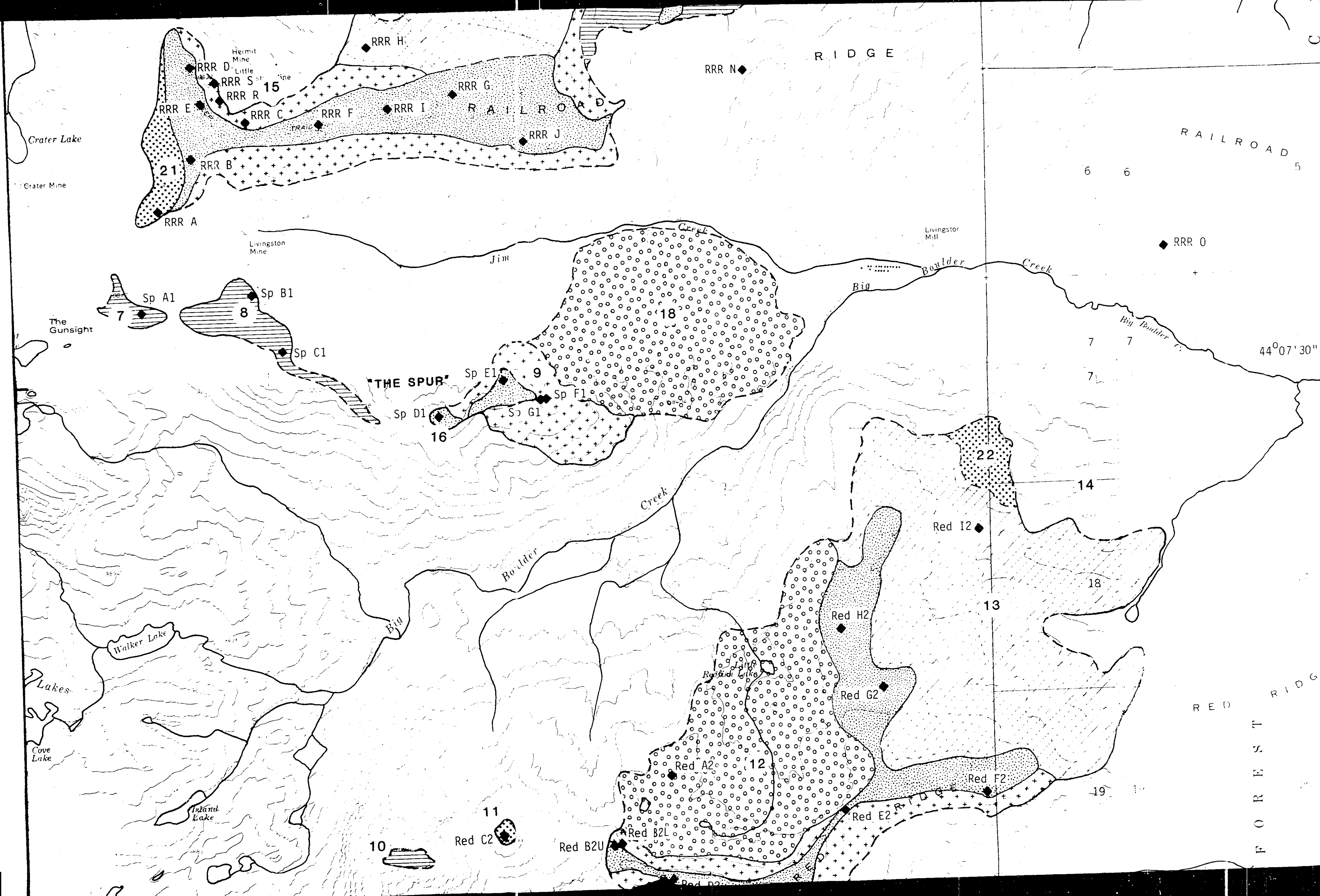
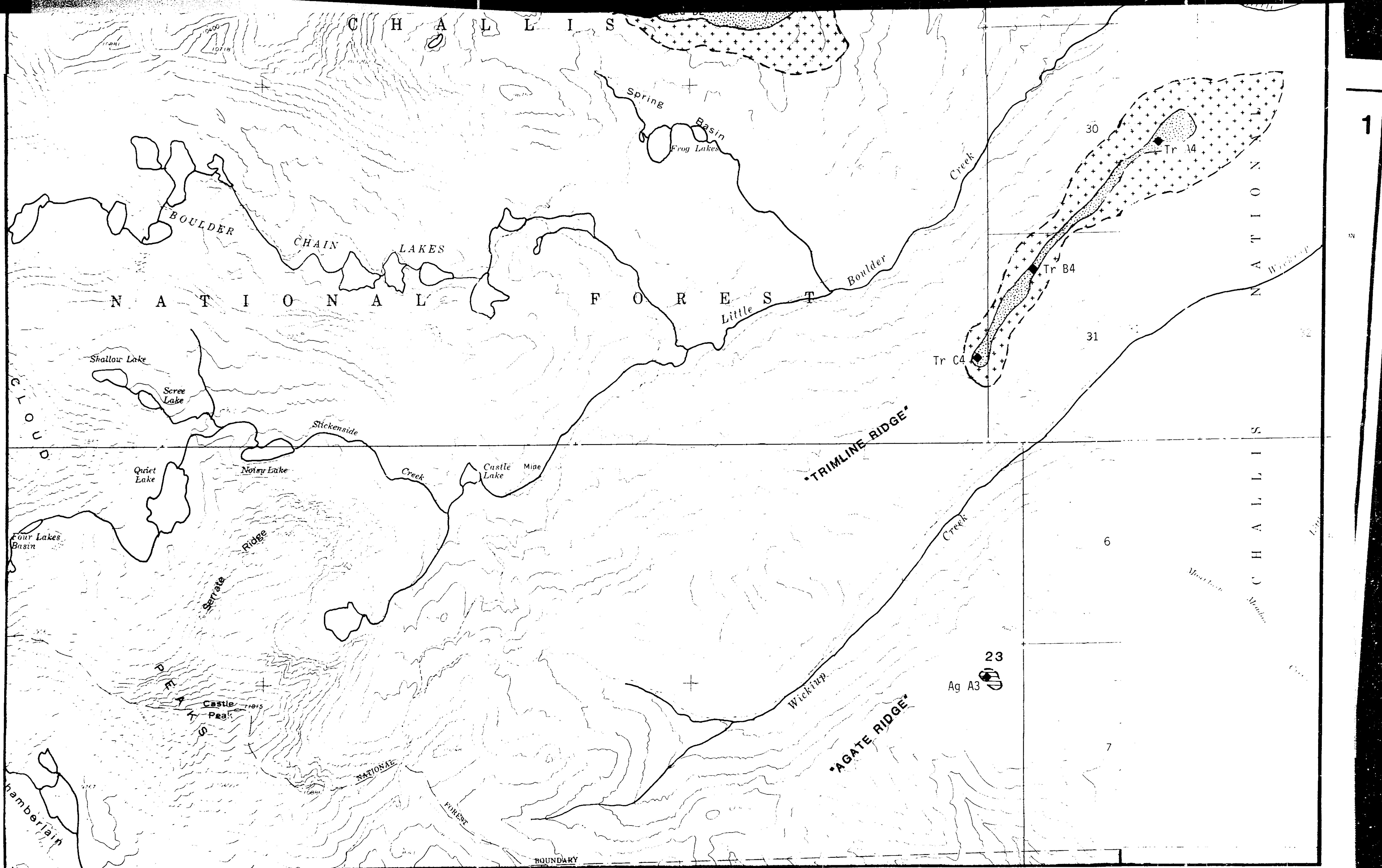
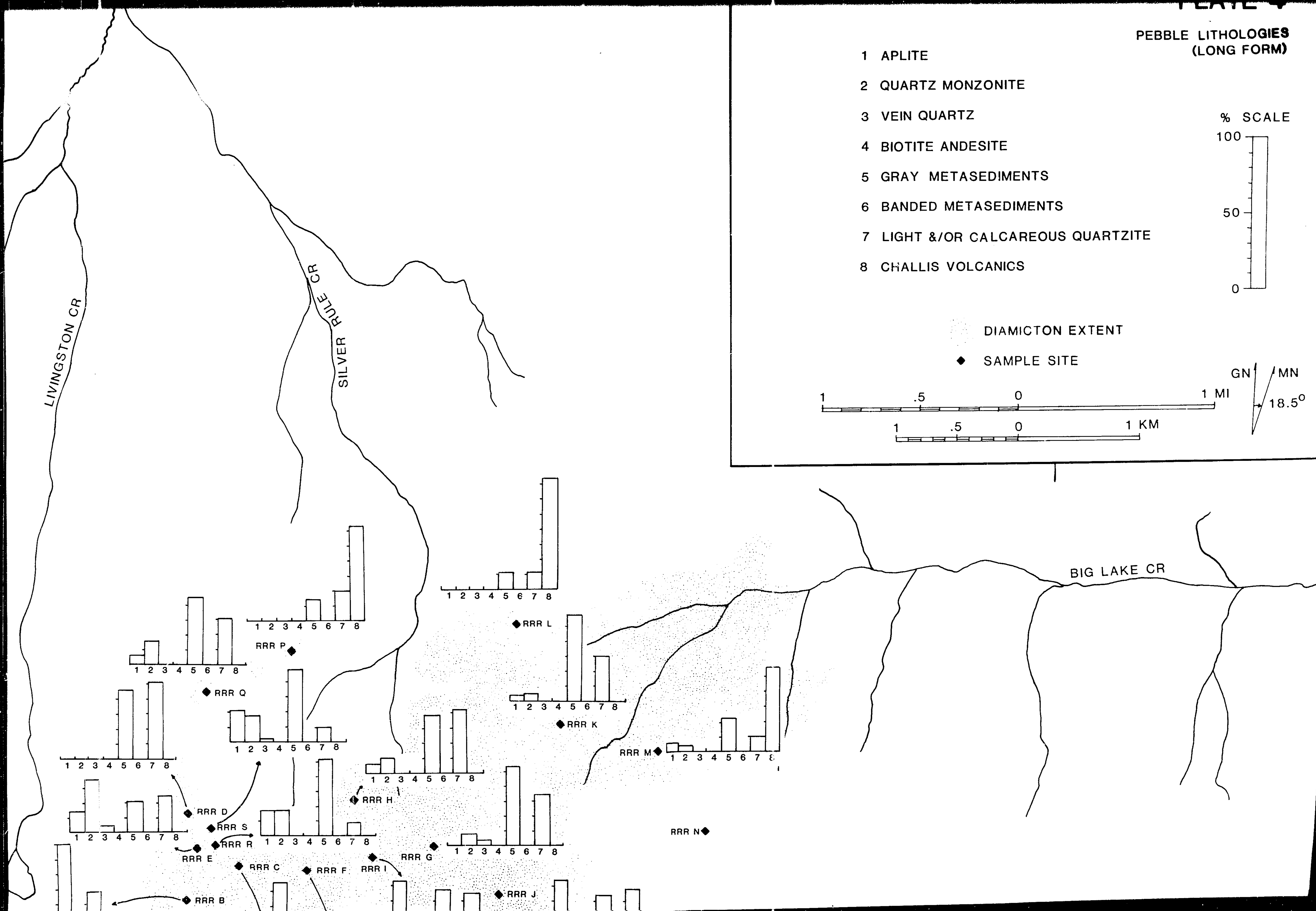


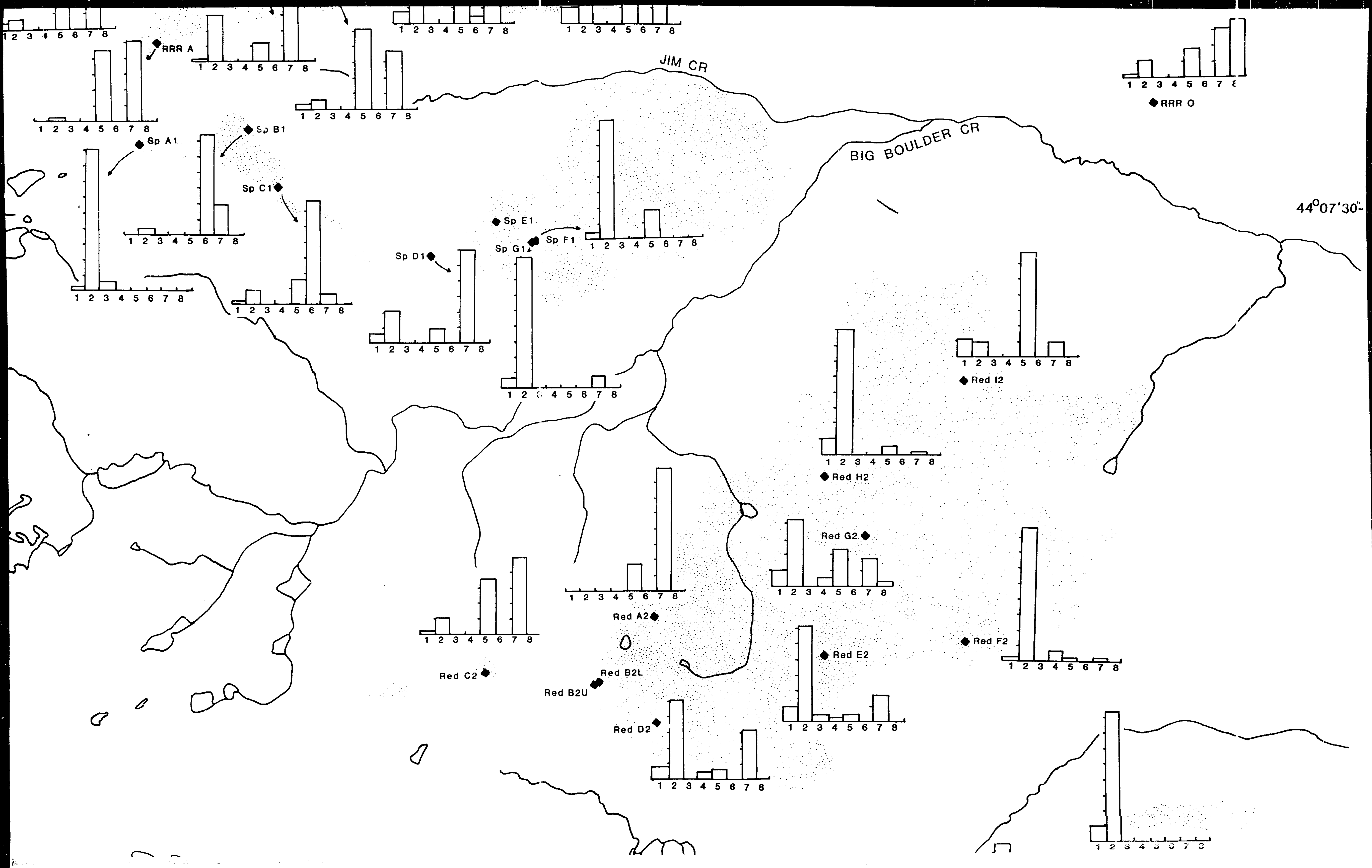
PLATE 1
LEGEND
"TYPICAL" DIAMICTON: quartz monzonite boulders in a matrix, with a flat ridgetop surface
ISOLATED BOULDERS: quartz monzonite boulders without matrix
DISSECTED DIAMICTON: diamicton eroded by post-depositional stream activity
COLLUVIATED DIAMICTON: mass-wasting diamicton in erosional escarpments
LANDSLIDE-TRANSPORTED DIAMICTON: diamicton transported by post-depositional landslides
ASSOCIATED DEPOSITS: deposits with a similar position and/or character as the Railroad Ridge diamicton
SAMPLE SITE
NUMBERS IN CIRCLES ARE LOCALITIES REFERRED TO IN THE TEXT
CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL
114°30'00"
CHALLIS
CHALLIS NATIONAL FORES
Silver Rule Creek
Carbonate Creek
Livingston Creek
Big Lake Creek
Spring
Coal
Calida Mine
Silver Rule Mine
Tango Mine
TRAIL
JEEP
RRR K
RRR L
RRR M
RRR P
RRR Q
1
2
3
4
5
6
17
19
20
29
30
31
32



RIDGE
RAILROAD
RAILROAD
RED RIDGE
FOREST
Crater Lake
Crater Mine
Hermit Mine
Little
RRR A
RRR B
RRR C
RRR D
RRR E
RRR F
RRR G
RRR H
RRR I
RRR J
RRR N
RRR O
RRR R
RRR S
TRAIL
15
21
Livingston Mine
Livingston Mill
Jim Creek
Big Boulder Creek
Big Boulder Cr.
44°07'30"
The Gunsight
Sp A1
Sp B1
Sp C1
Sp D1
Sp E1
Sp F1
Sp G1
"THE SPUR"
7
8
9
16
18
22
14
13
12
11
10
19
Red I2
Red H2
Red G2
Red F2
Red E2
Red A2
Red B2L
Red B2U
Red C2
Little Redfish Lake
Walker Lake
Lakes
Cove Lake
Island Lake


1
CHALLIS NATIONAL FOREST
Spring Basin
Frog Lakes
BOULDER CHAIN LAKES
Little Boulder Creek
Shallow Lake
Scree Lake
Stickenside Creek
Quiet Lake
Noisy Lake
Castle Lake
Mine
Four Lakes Basin
CLOUD
Serrate Ridge
PEAKS
Castle Peak
11815
NATIONAL FOREST BOUNDARY
Chamberlain
"TRIMLINE RIDGE"
"AGATE RIDGE"
Wickiup Creek
Creek
Tr A4
Tr B4
Tr C4
Ag A3
23
30
31
6
7


PEBBLE LITHOLOGIES
(LONG FORM)
1 APLITE
2 QUARTZ MONZONITE
3 VEIN QUARTZ
4 BIOTITE ANDESITE
5 GRAY METASEDIMENTS
6 BANDED METASEDIMENTS
7 LIGHT &/OR CALCAREOUS QUARTZITE
8 CHALLIS VOLCANICS
% SCALE
100
50
0
DIAMICTON EXTENT
SAMPLE SITE
GN
MN
18.5°
1 .5 0 1 MI
1 .5 0 1 KM
LIVINGSTON CR
SILVER RULE CR
BIG LAKE CR
RRR B
RRR C
RRR D
RRR E
RRR F
RRR G
RRR H
RRR I
RRR J
RRR K
RRR L
RRR M
RRR N
RRR P
RRR Q
RRR R
RRR S



JIM CR
BIG BOULDER CR
44°07'30"
RRR A
RRR O
Sp A1
Sp B1
Sp C1
Sp D1
Sp E1
Sp F1
Sp G1
Red A2
Red B2L
Red B2U
Red C2
Red D2
Red E2
Red F2
Red G2
Red H2
Red I2

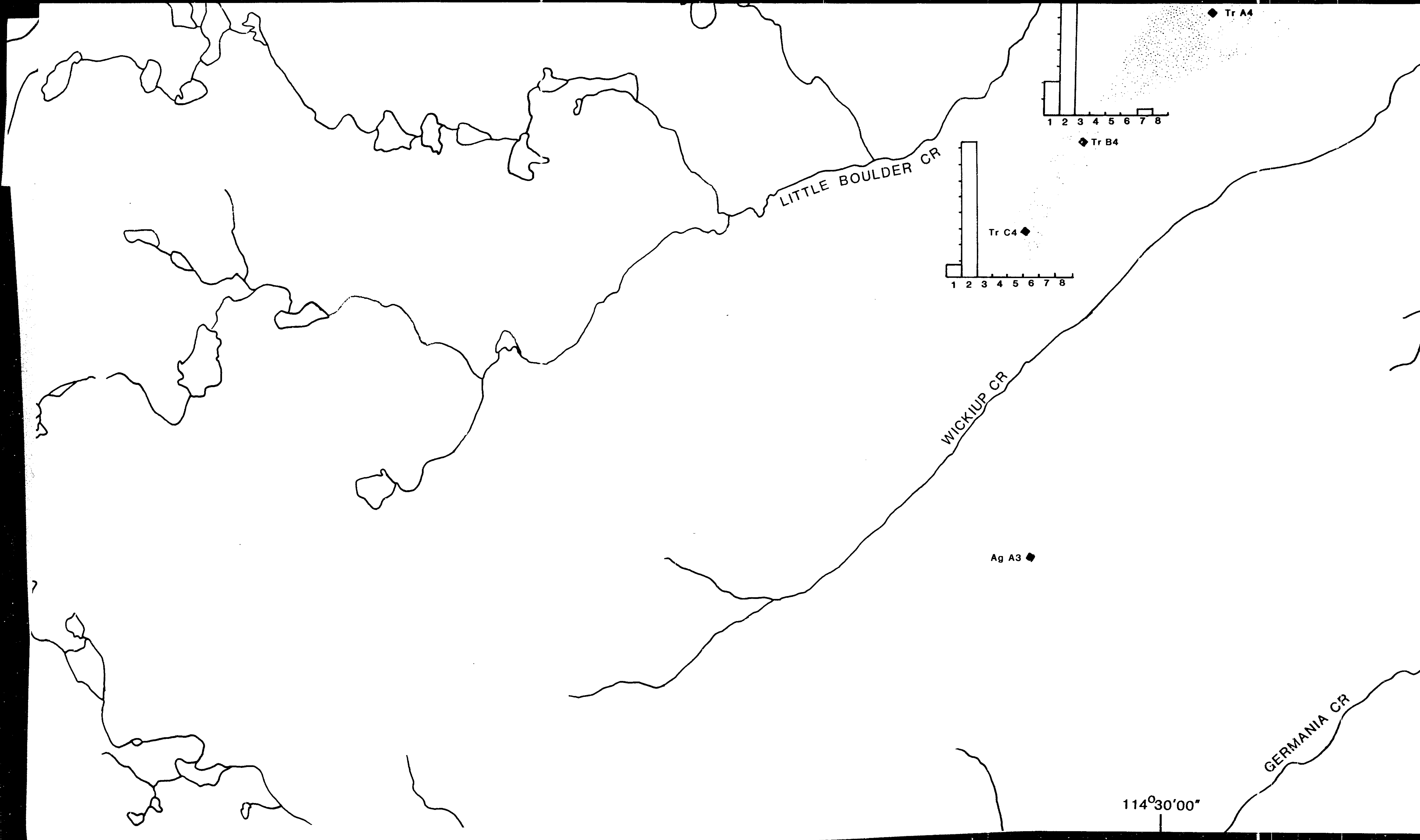
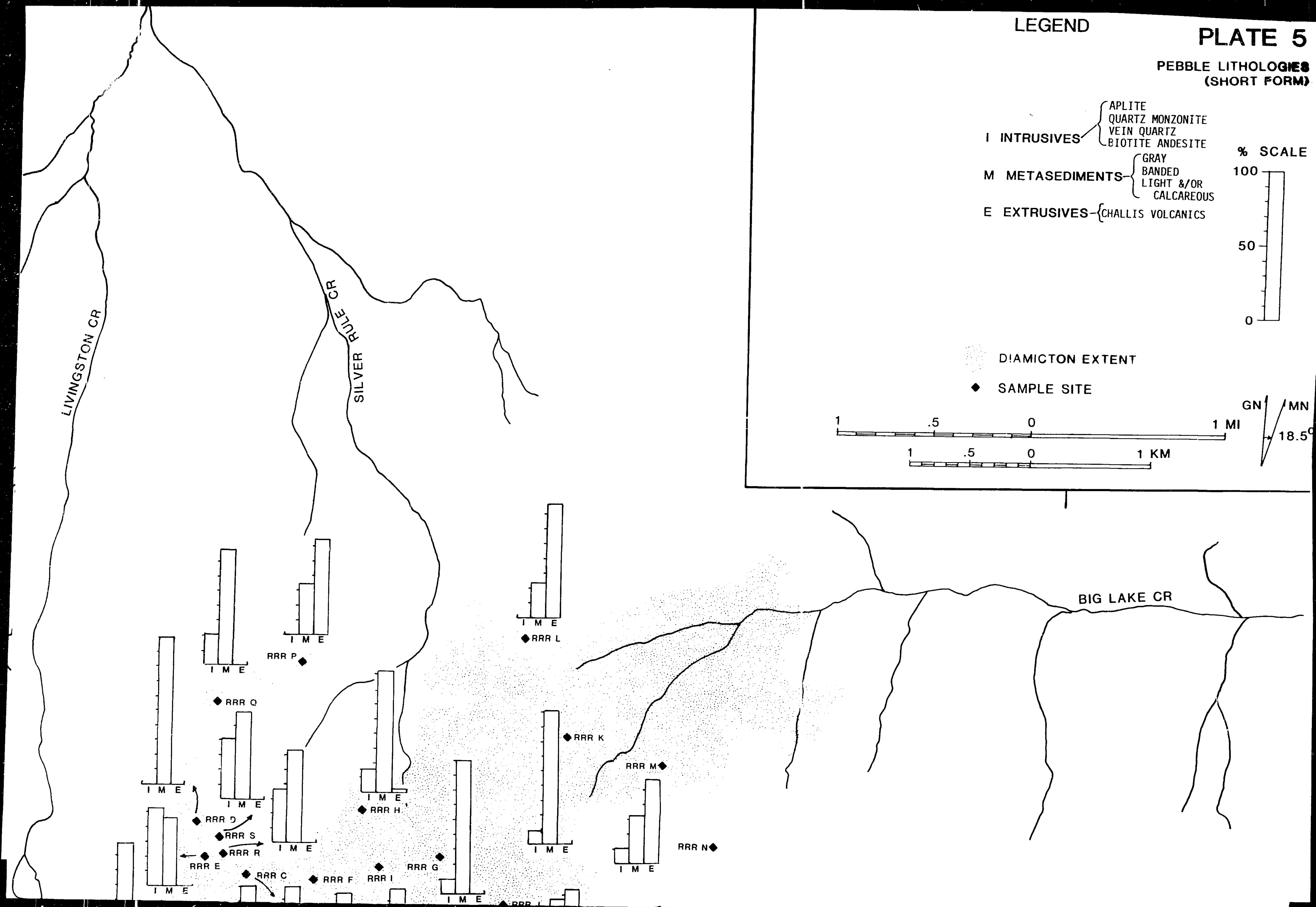

Tr A4
1 2 3 4 5 6 7 8
Tr B4
LITTLE BOULDER CR
Tr C4
1 2 3 4 5 6 7 8
WICKIUP CR
Ag A3
GERMANIA CR
114°30'00"

PLATE 5

PEBBLE LITHOLOGIES
(SHORT FORM)



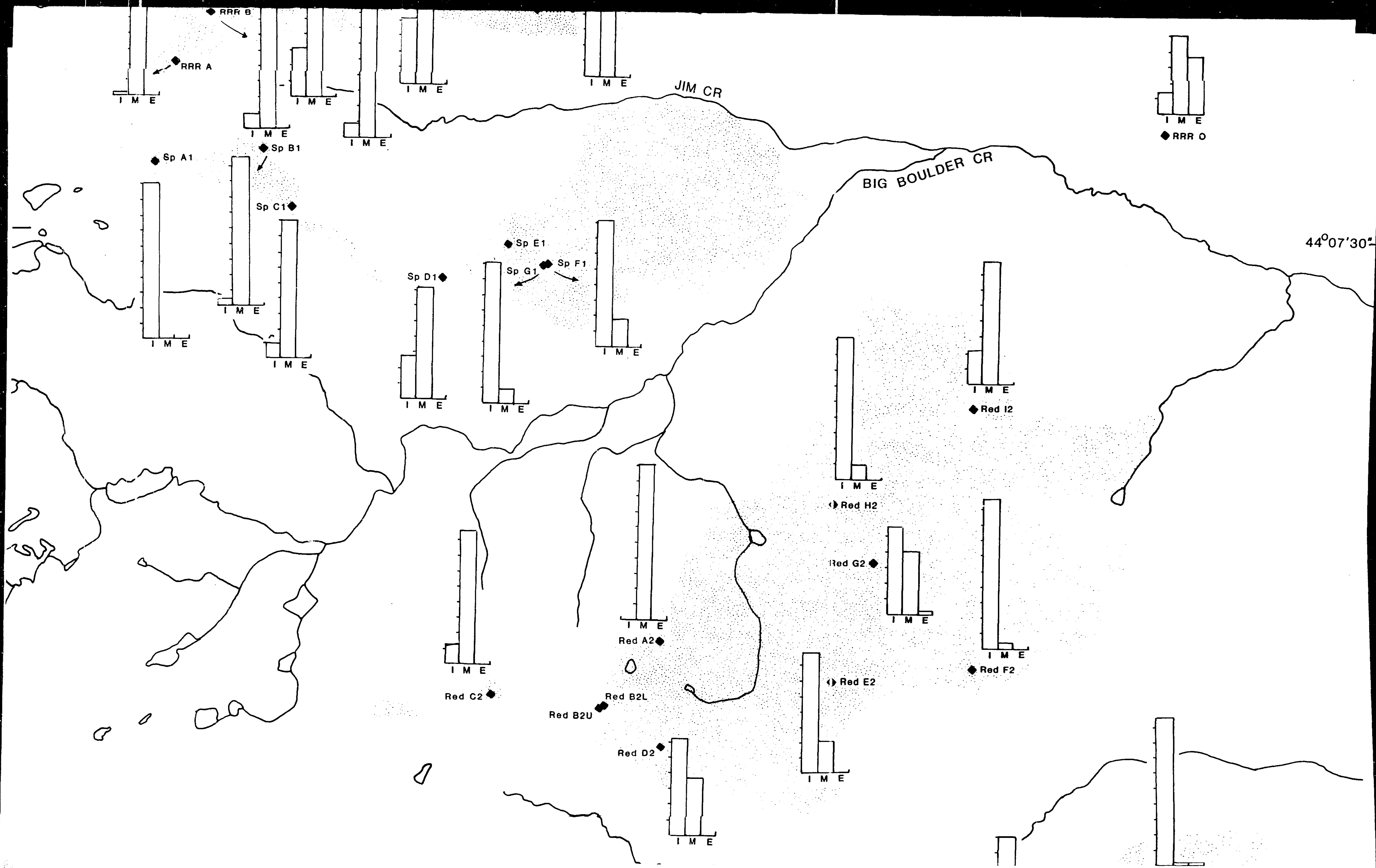
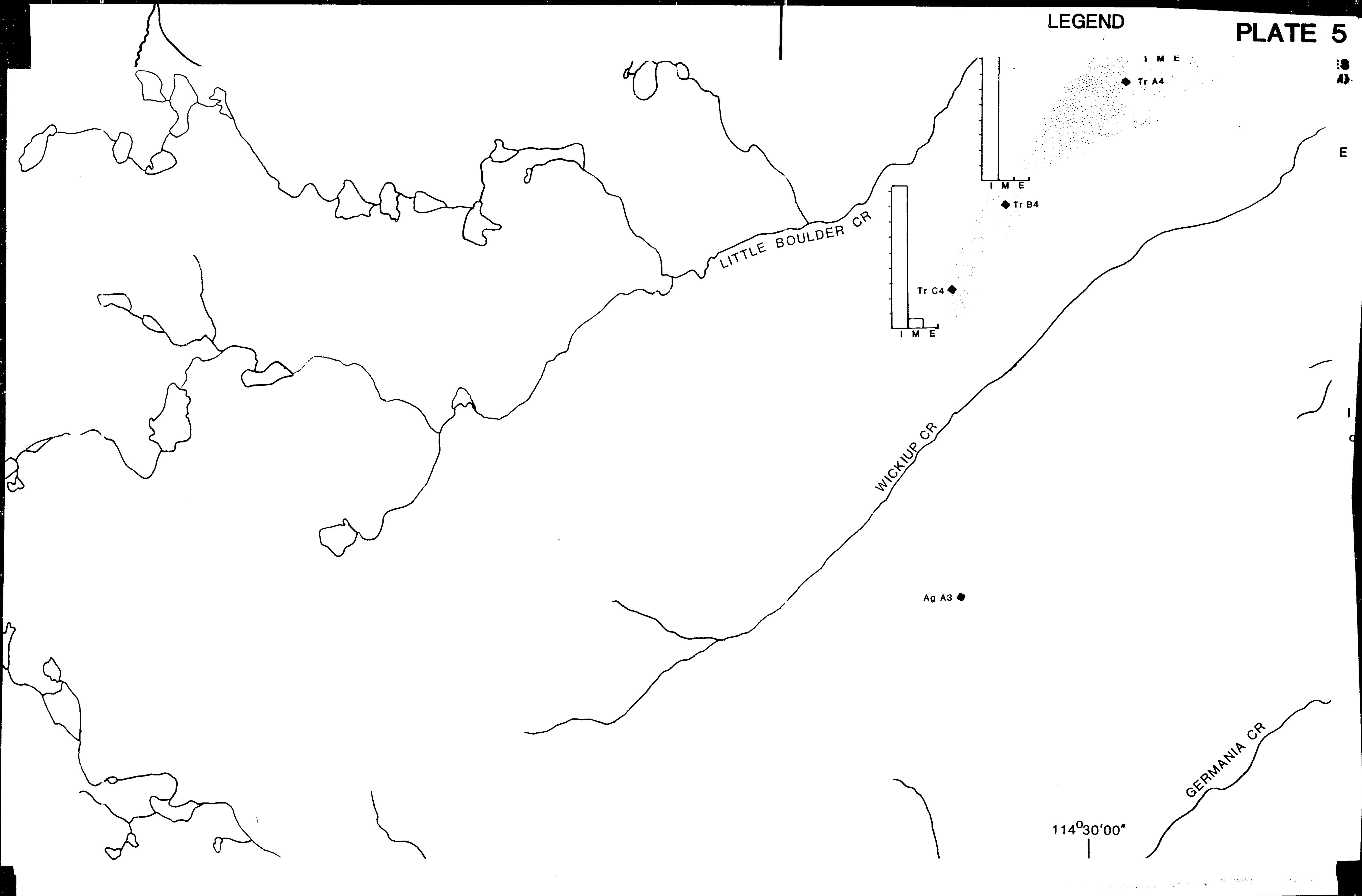
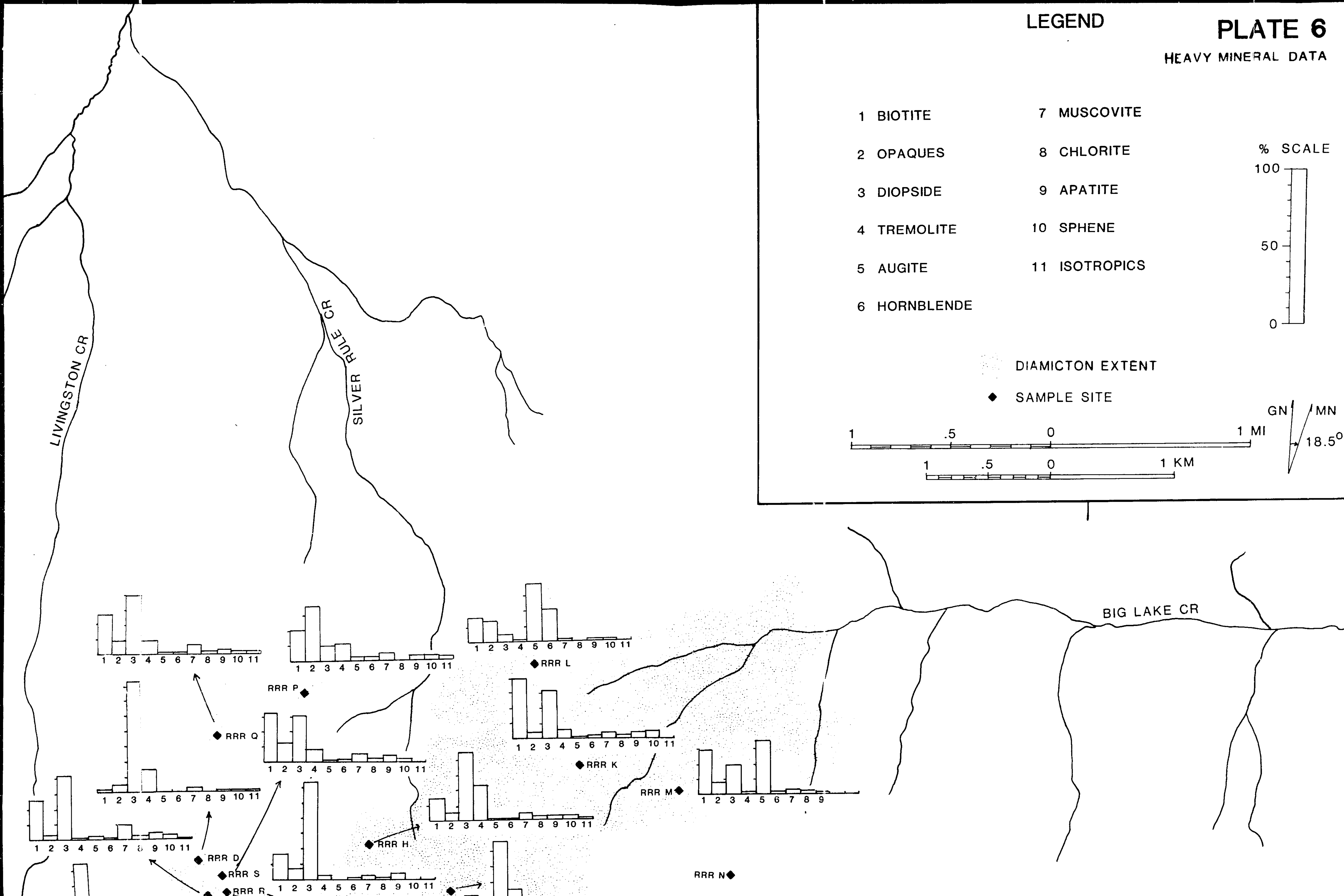
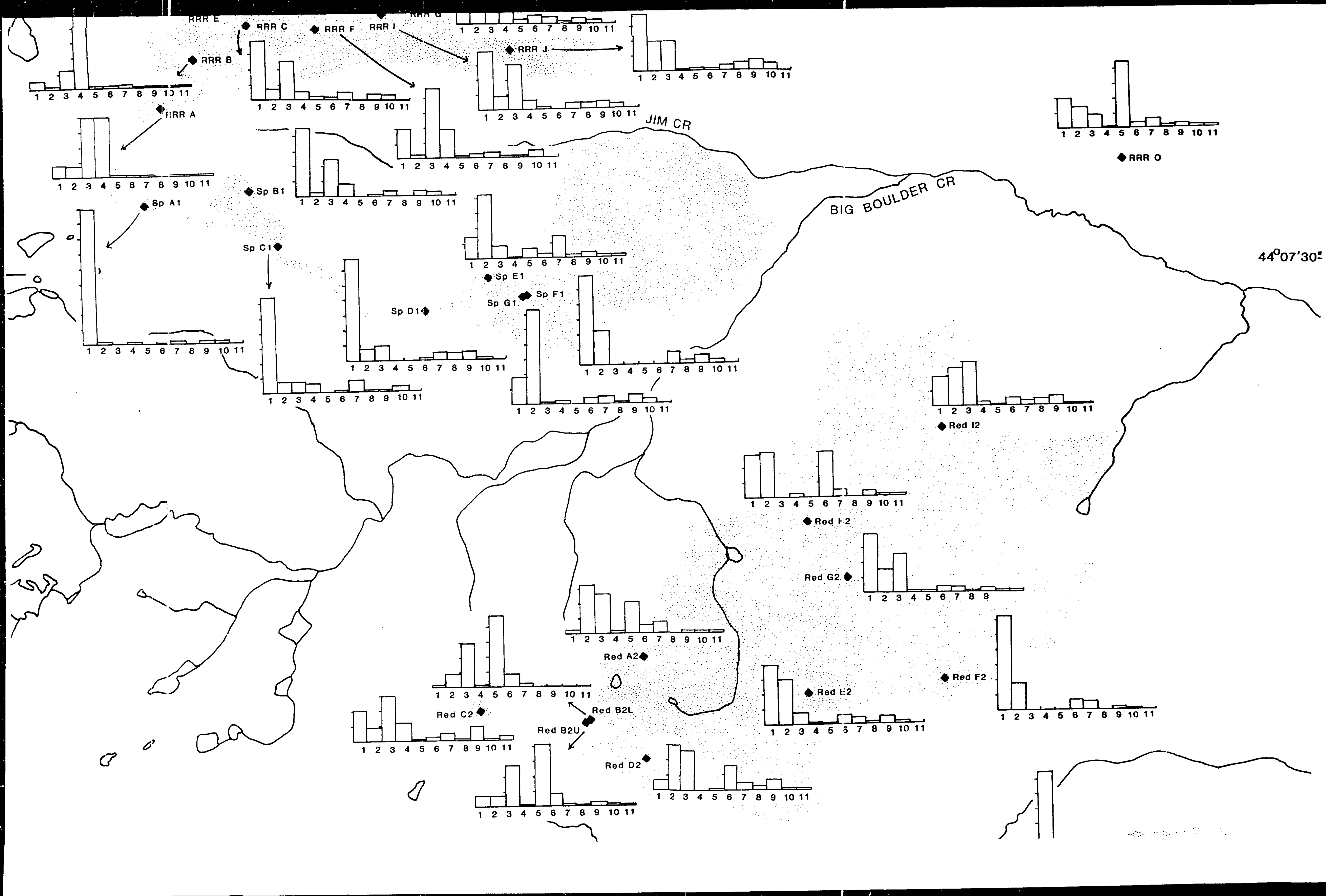

JIM CR
BIG BOULDER CR
44°07'30"
RRR A
RRR B
RRR O
Sp A1
Sp B1
Sp C1
Sp D1
Sp E1
Sp F1
Sp G1
Red A2
Red B2L
Red B2U
Red C2
Red D2
Red E2
Red F2
Red G2
Red H2
Red I2
I M E

PLATE 5



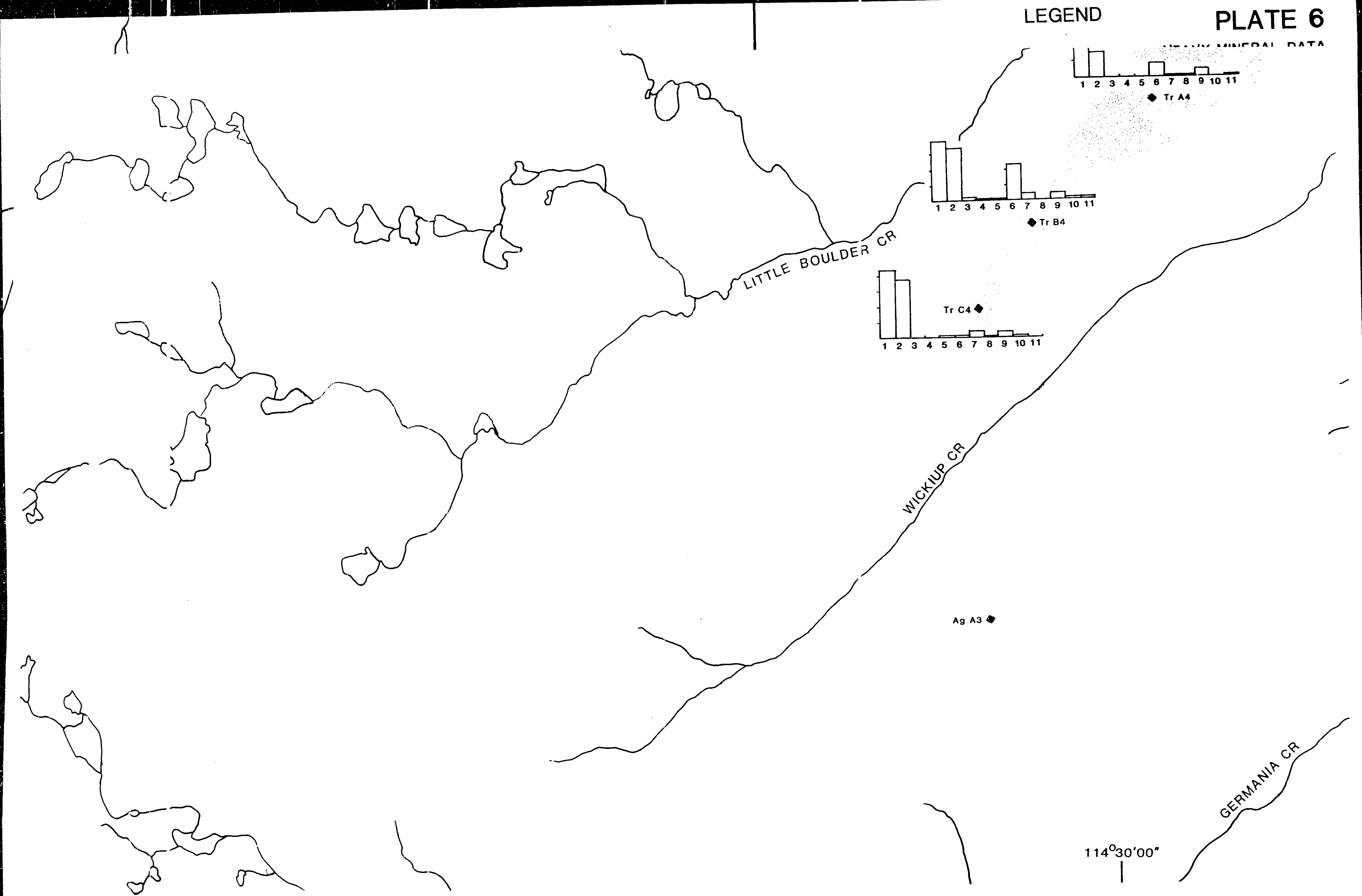
LEGEND
I M E
Tr A4
Tr B4
Tr C4
Ag A3
LITTLE BOULDER CR
WICKIUP CR
GERMANIA CR
114°30'00"
E


LEGEND
PLATE 6
HEAVY MINERAL DATA
1 BIOTITE
2 OPAQUES
3 DIOPSIDE
4 TREMOLITE
5 AUGITE
6 HORNBLENDE
7 MUSCOVITE
8 CHLORITE
9 APATITE
10 SPHENE
11 ISOTROPICS
% SCALE
100
50
0
DIAMICTON EXTENT
SAMPLE SITE
1 .5 0 1 MI
1 .5 0 1 KM
GN
MN
18.5°
LIVINGSTON CR
SILVER RULE CR
BIG LAKE CR
RRR P
RRR Q
RRR L
RRR K
RRR M
RRR N
RRR H
RRR D
RRR S
RRR R



RRR E
RRR C
RRR F
RRR I
RRR B
RRR J
RRR A
RRR O
Sp A1
Sp B1
Sp C1
Sp D1
Sp E1
Sp F1
Sp G1
JIM CR
BIG BOULDER CR
44°07'30"
Red I2
Red F2
Red G2
Red A2
Red C2
Red B2L
Red B2U
Red E2
Red F2
Red D2

PLATE 6


LEGEND
1 2 3 4 5 6 7 8 9 10 11
Tr A4
1 2 3 4 5 6 7 8 9 10 11
Tr B4
LITTLE BOULDER CR
Tr C4
1 2 3 4 5 6 7 8 9 10 11
WICKIUP CR
Ag A3
GERMANIA CR
114°30'00"